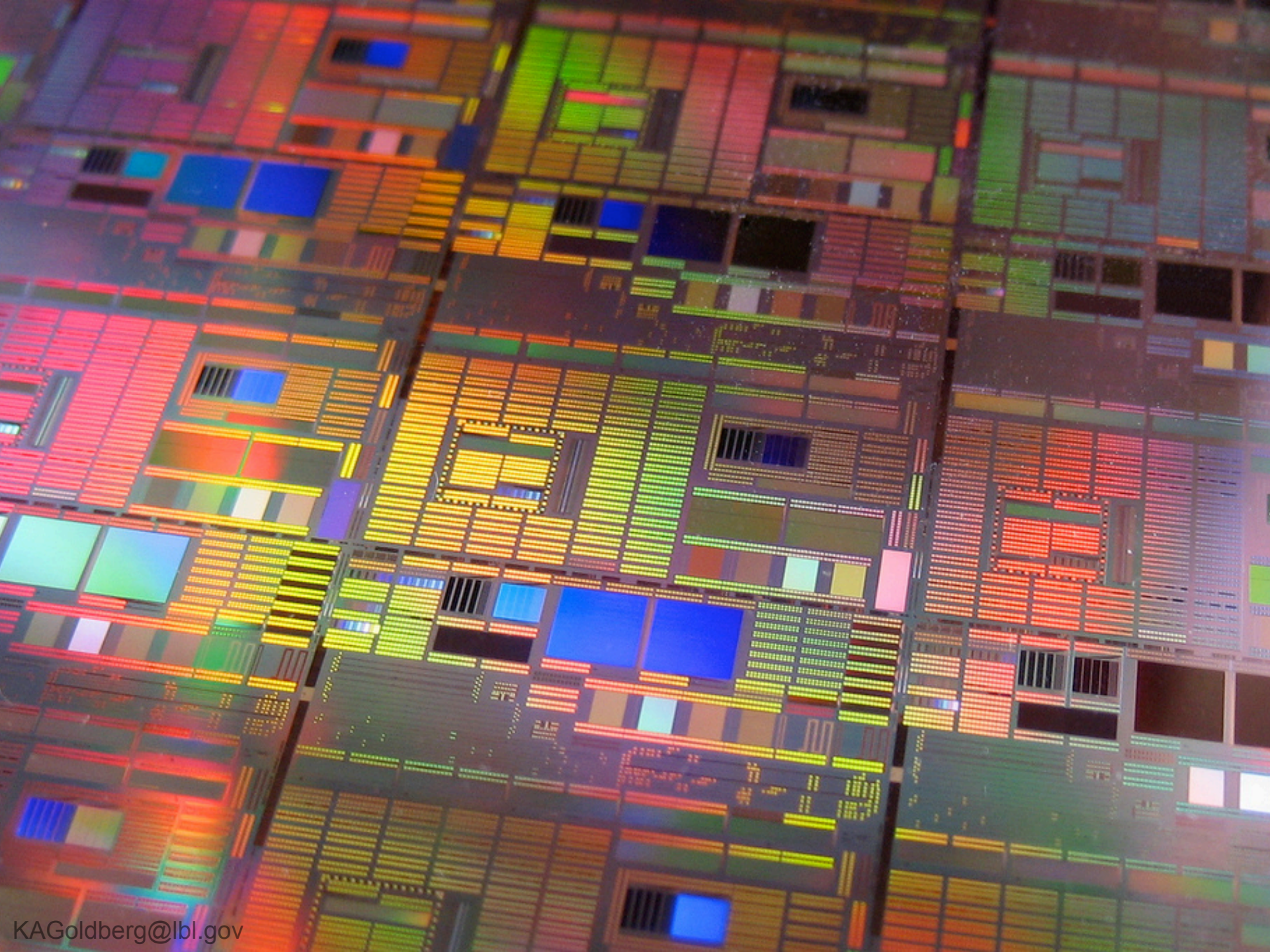


# Creating an EUV Mask Microscope for Lithography generations Reaching 8 nm

**Kenneth Goldberg**

Deputy Director, Center for X-Ray Optics  
Lawrence Berkeley National Laboratory

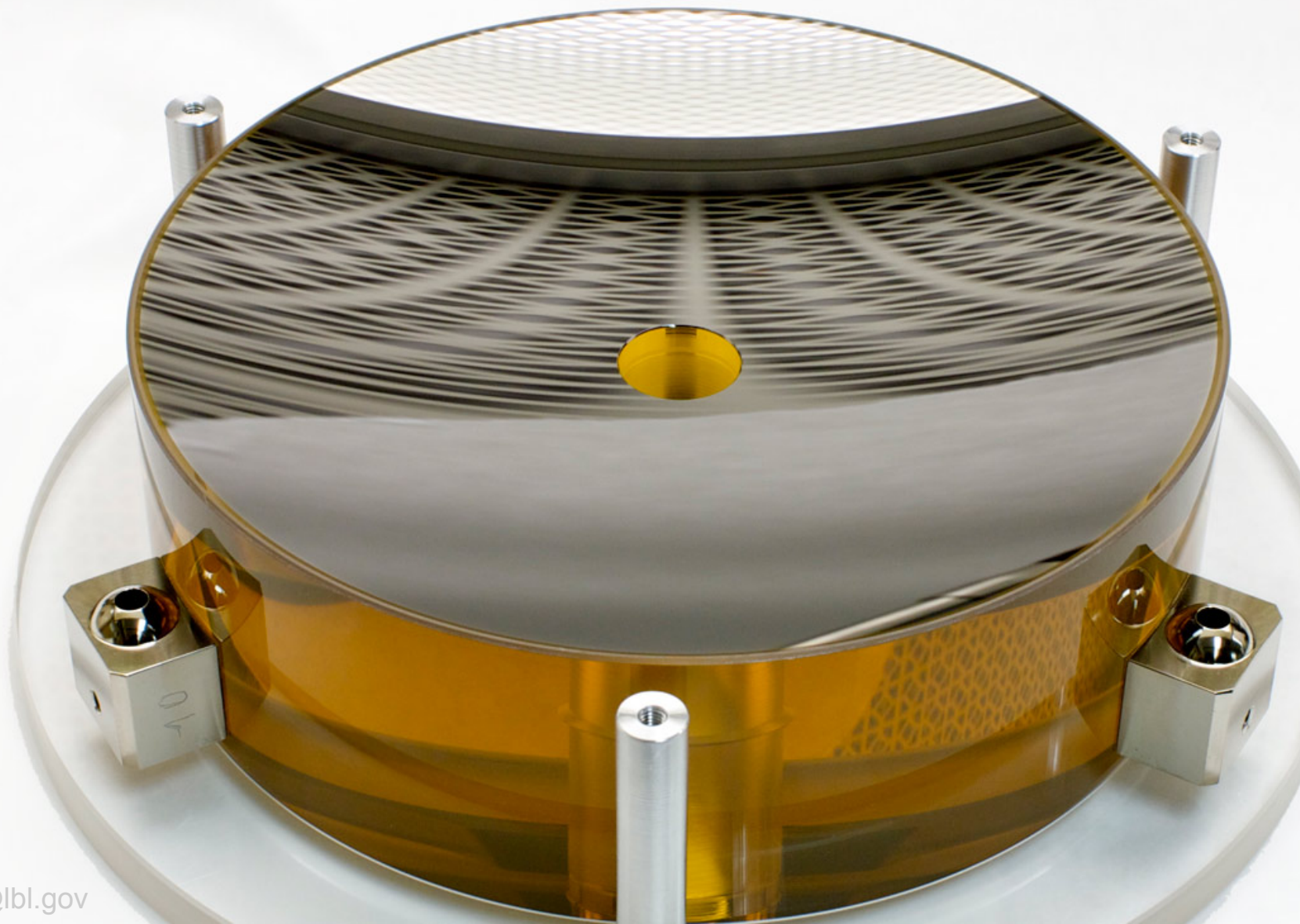




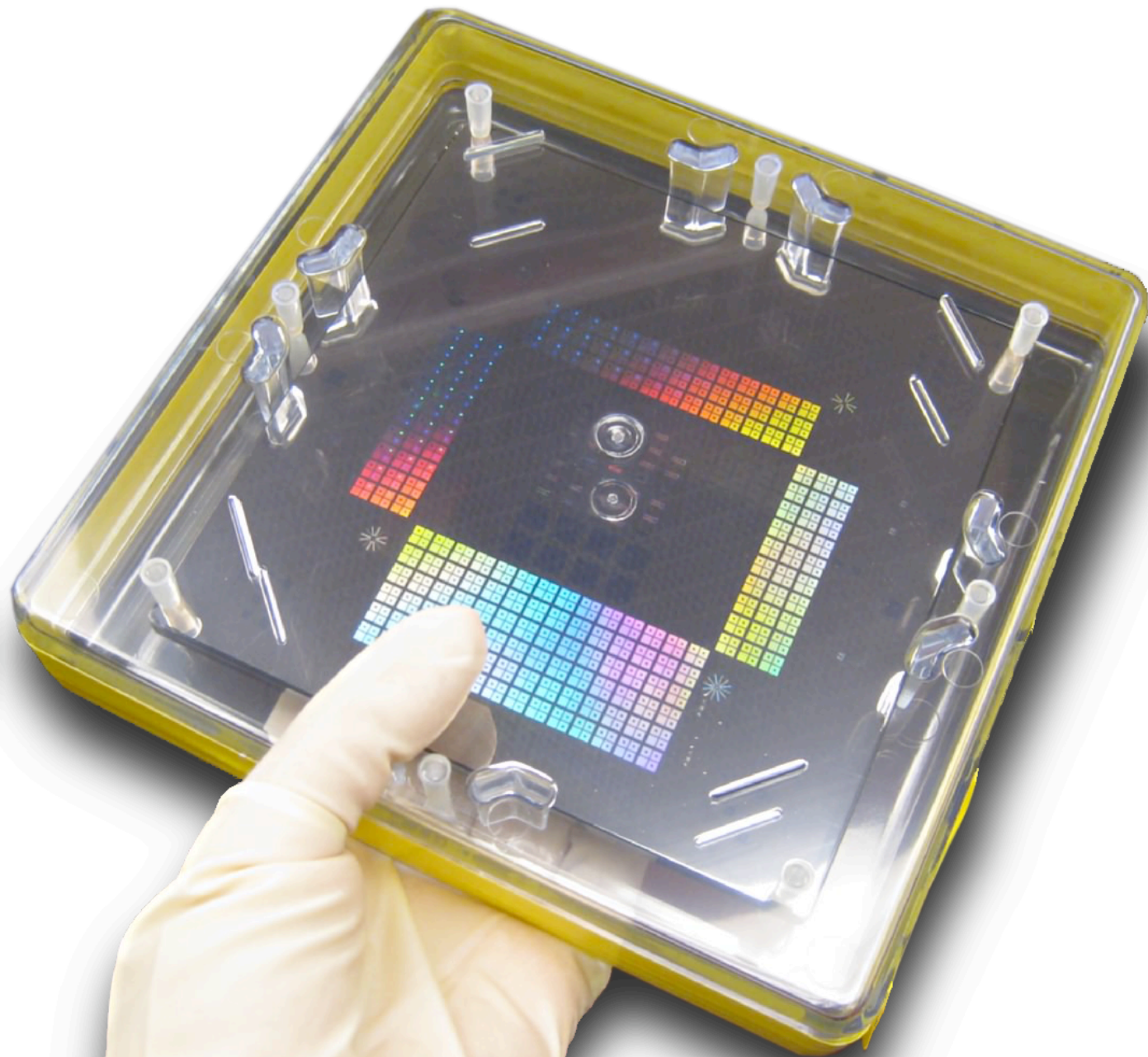
# EUV is COMING



ALL PAPER MADE by 7KINGDOMS.RU (based on official art)



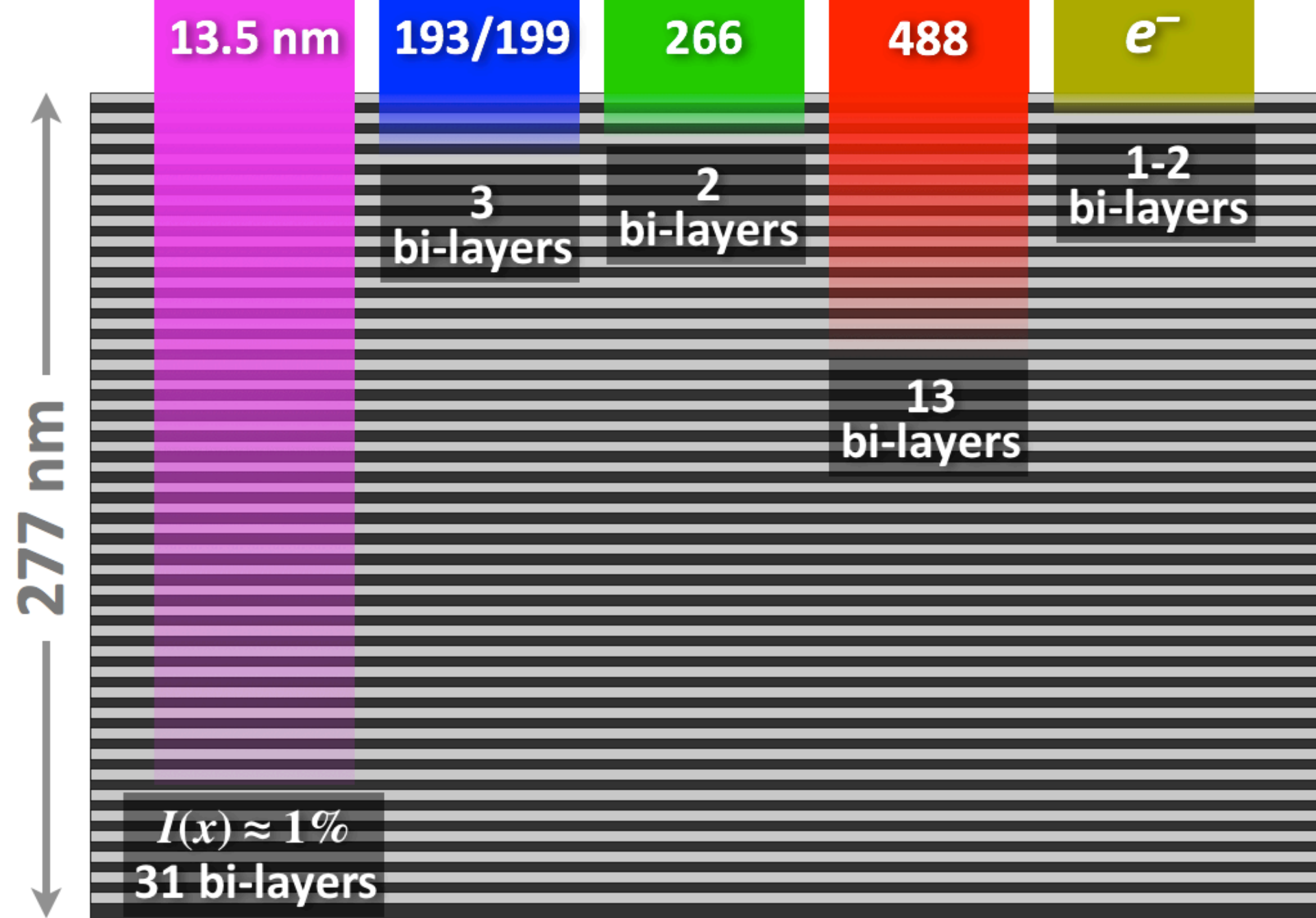












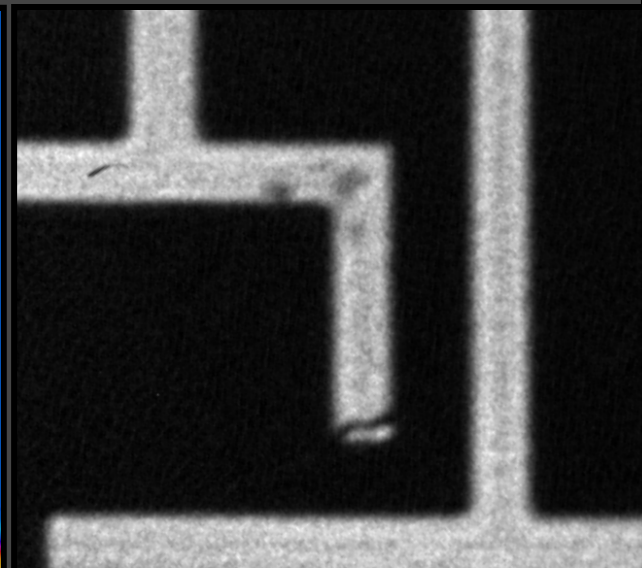
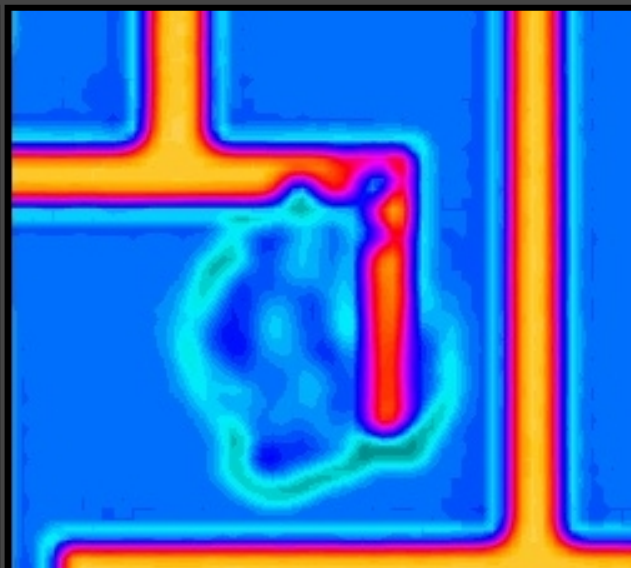
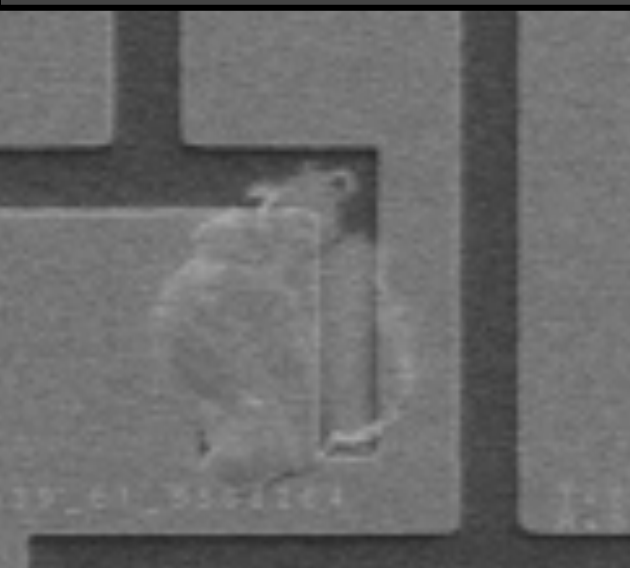
**SEM**

KLA 587

**DUV**

AIT

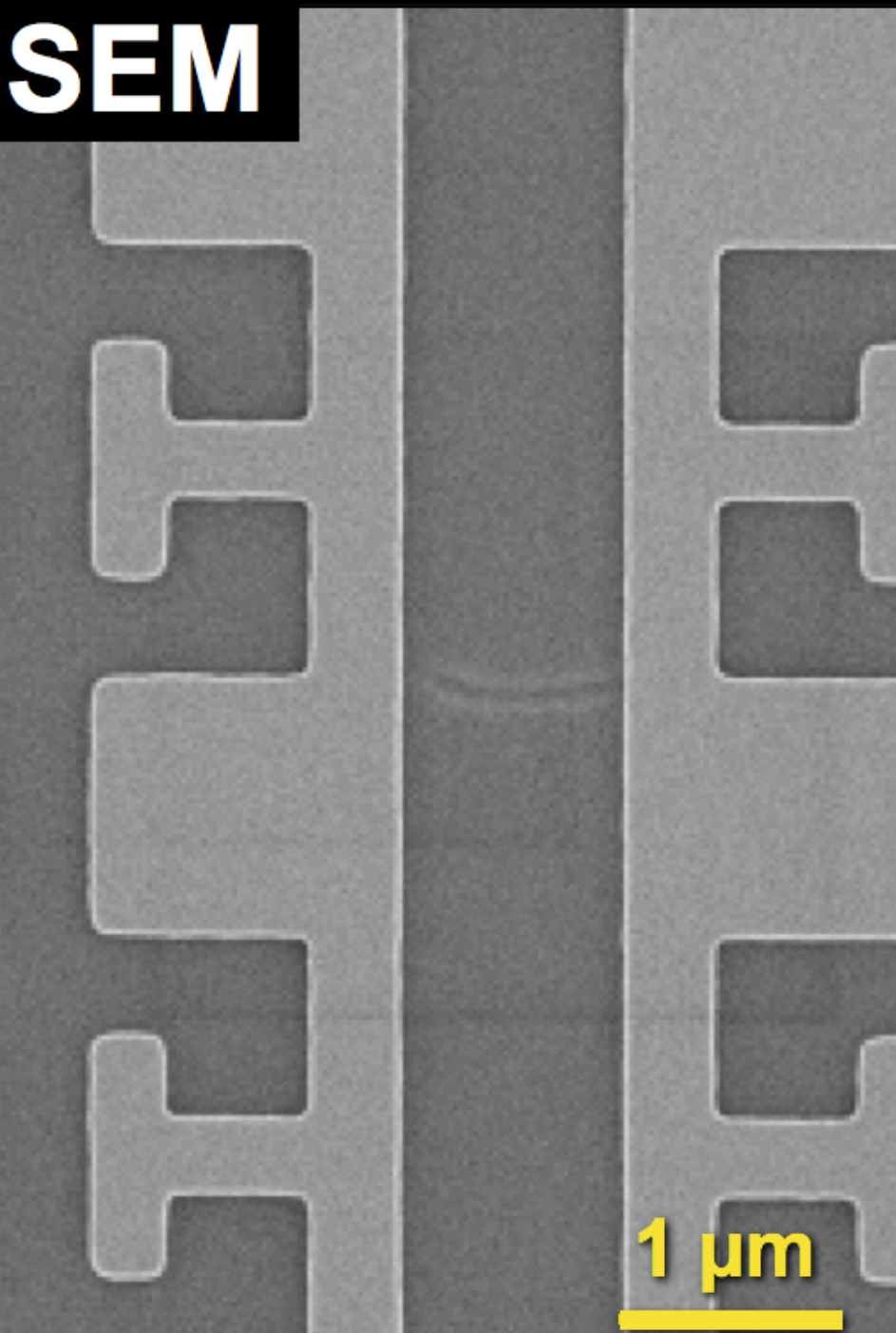
**EUV**



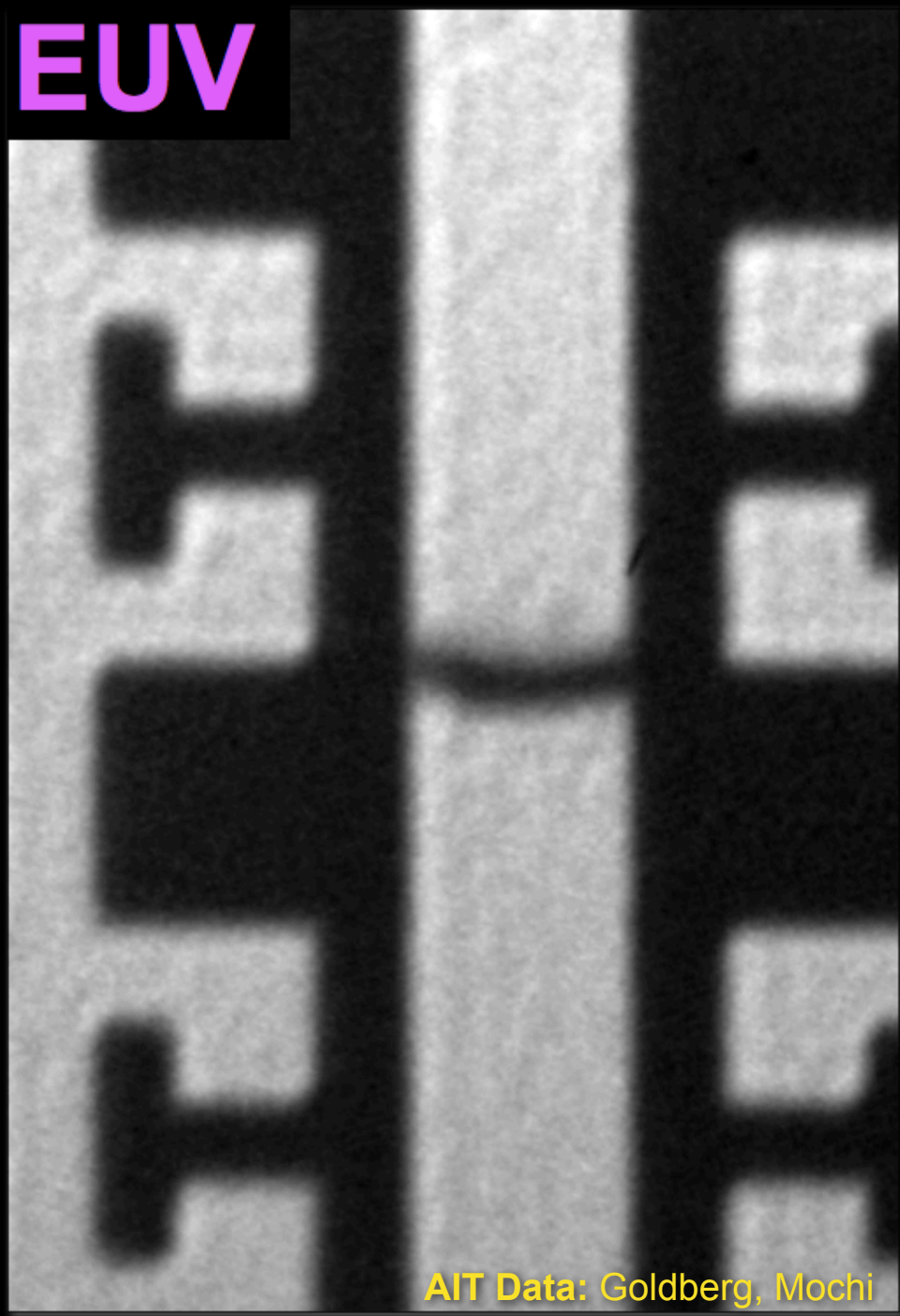
1  $\mu\text{m}$



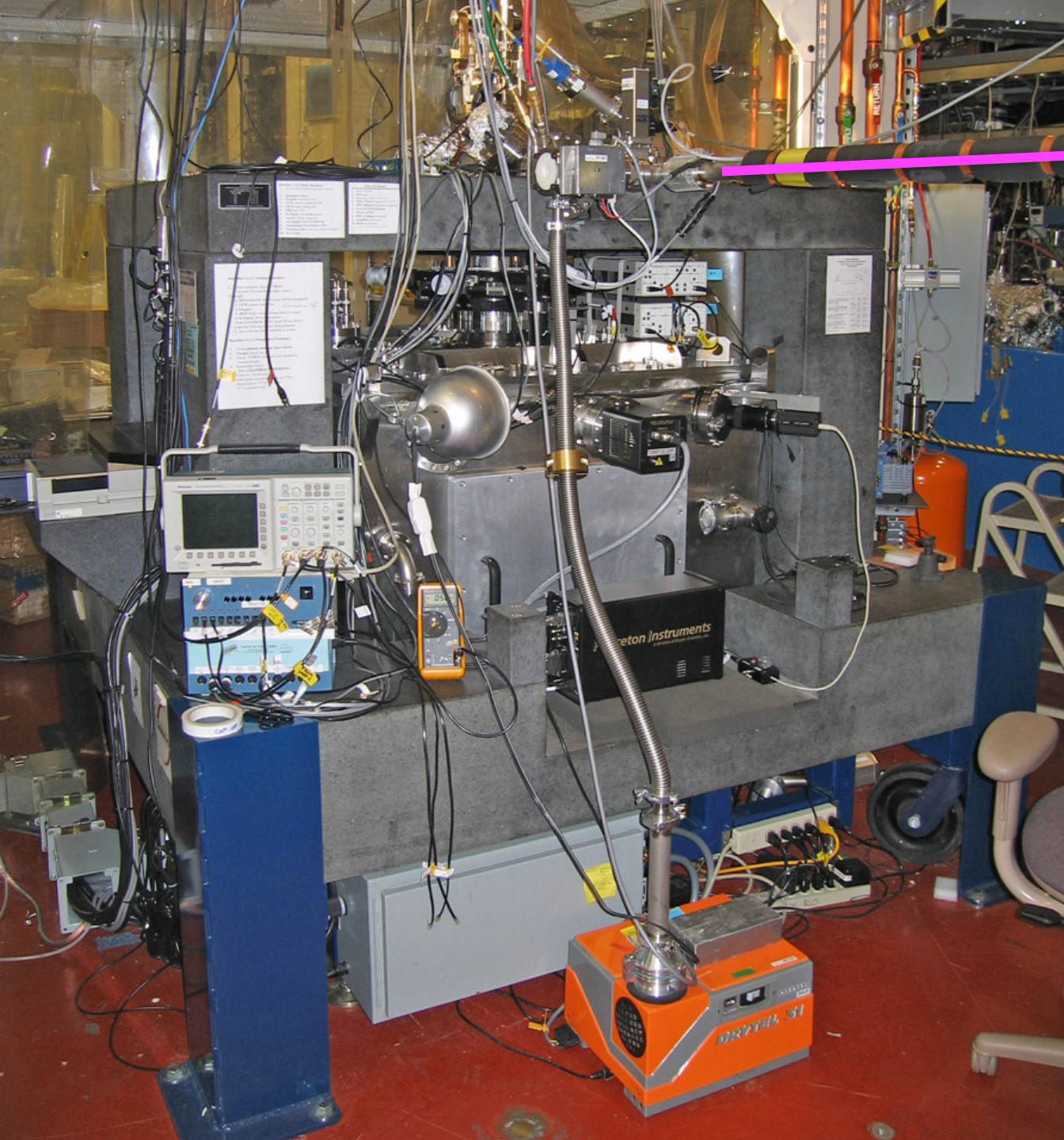
**SEM**



**EUV**



AIT Data: Goldberg, Mochi



**The AIT**



# The SEMATECH Berkeley Actinic Inspection Tool (AIT)

$\lambda$ : 13.2–13.6 nm

NA (4x): 0.25–0.35,  $\angle 6^\circ$

Mag: 907x

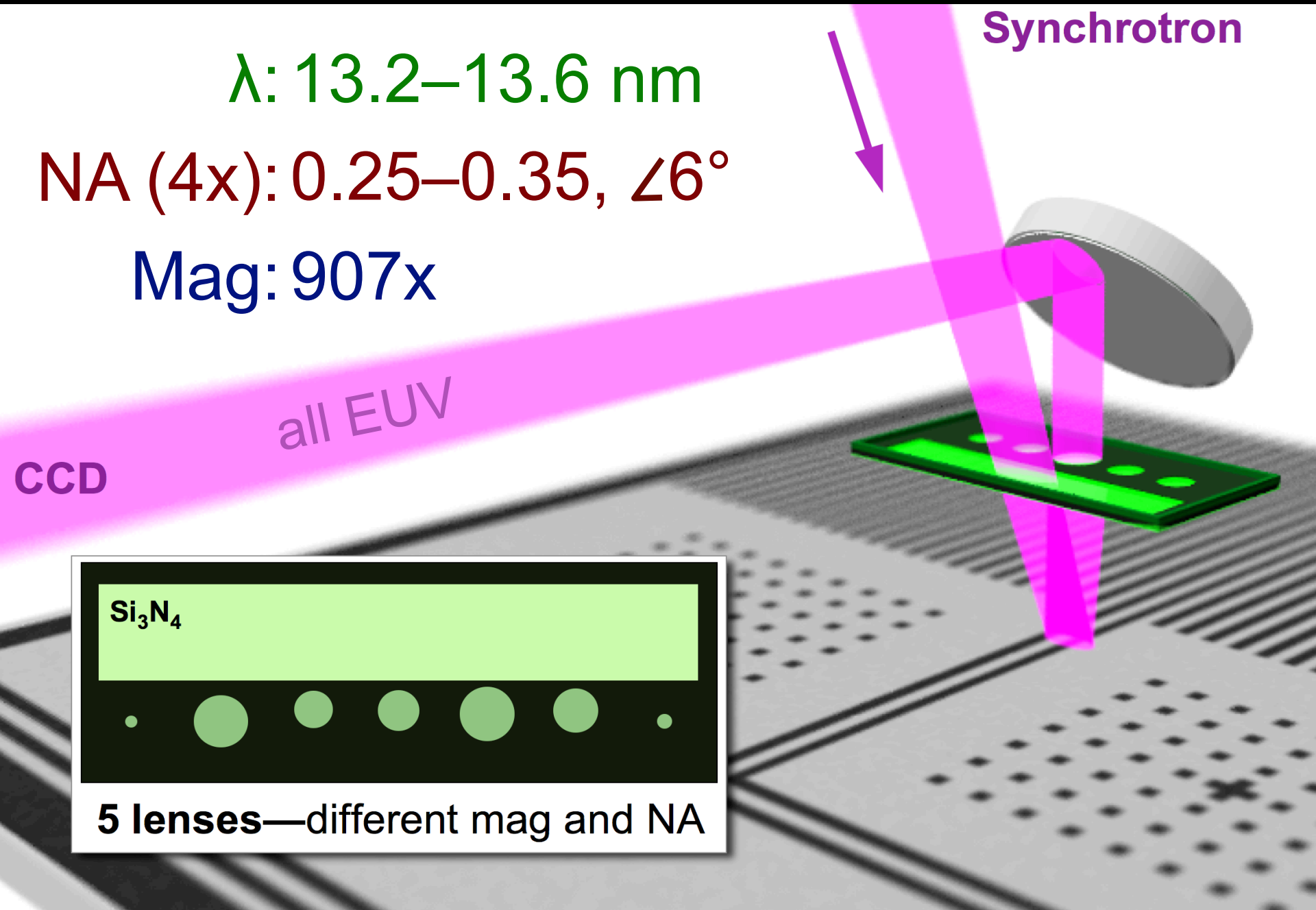
Synchrotron

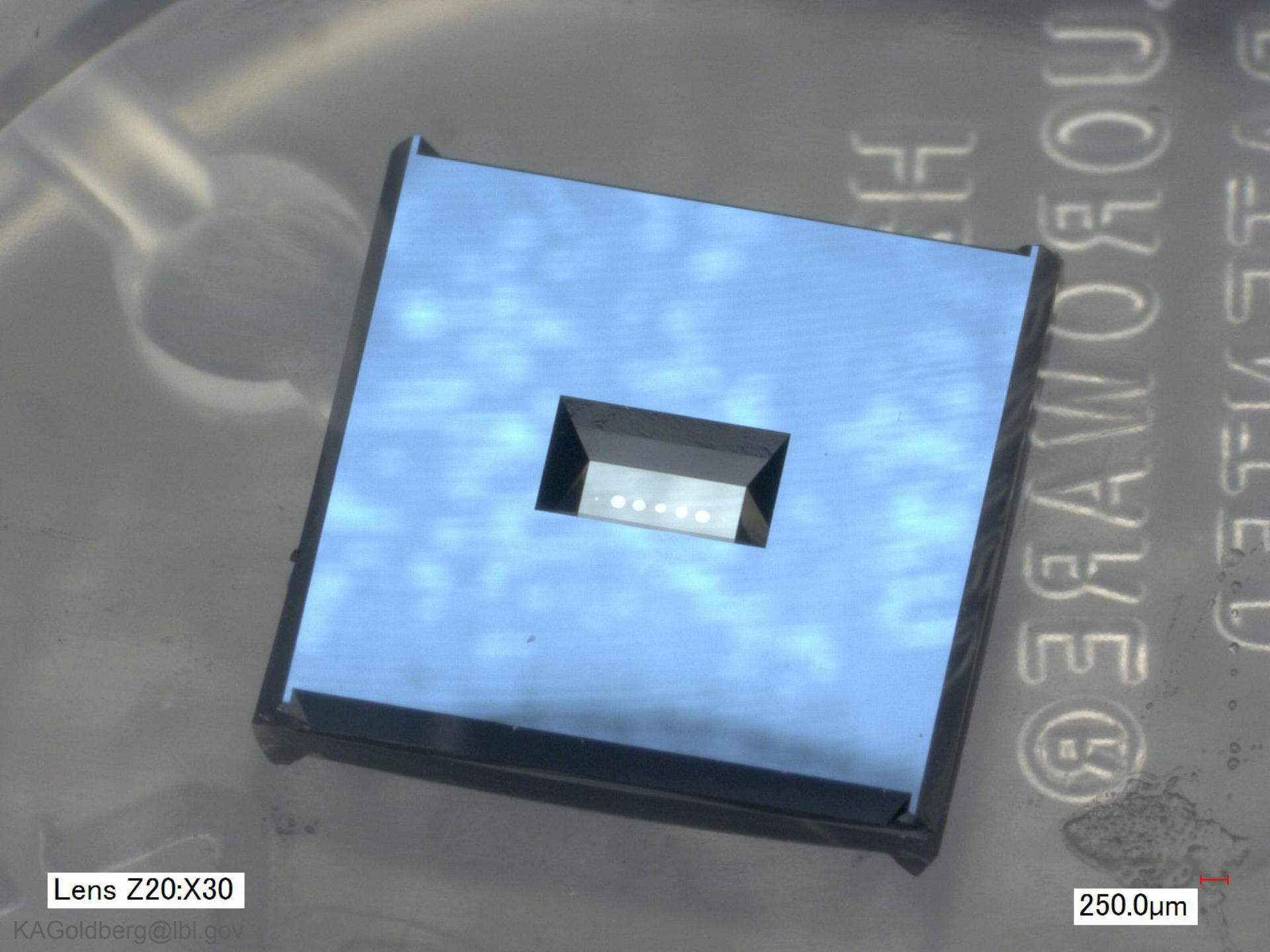
all EUV

CCD

$\text{Si}_3\text{N}_4$

5 lenses—different mag and NA

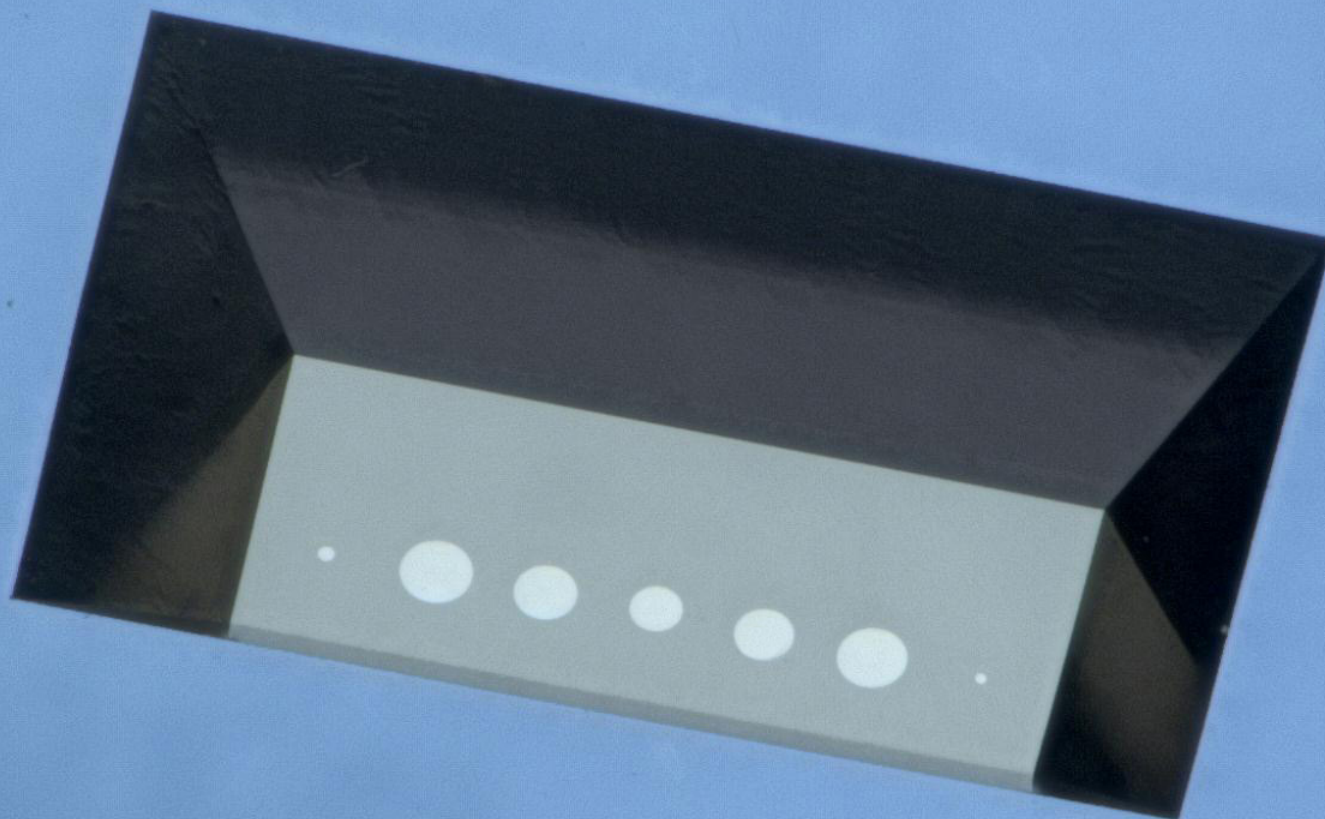




Lens Z20:X30

250.0µm





Lens Z20:X100

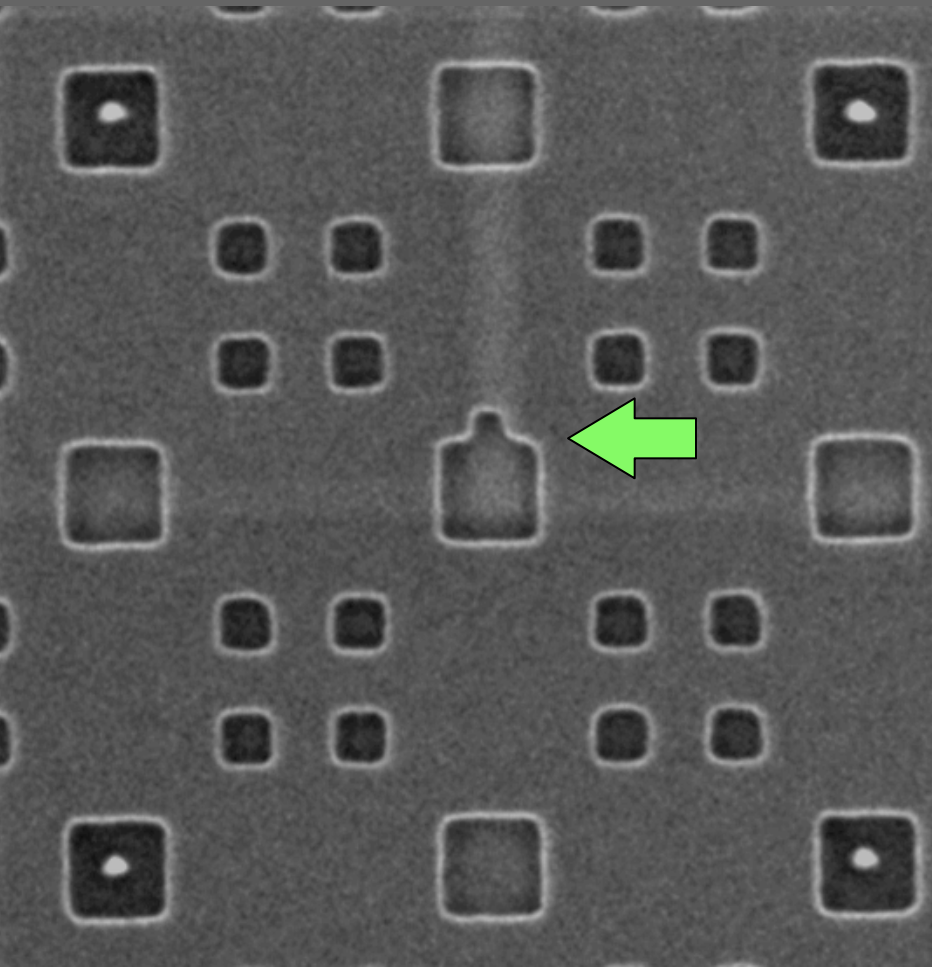
KAGoldberg@lbl.gov

250.0μm

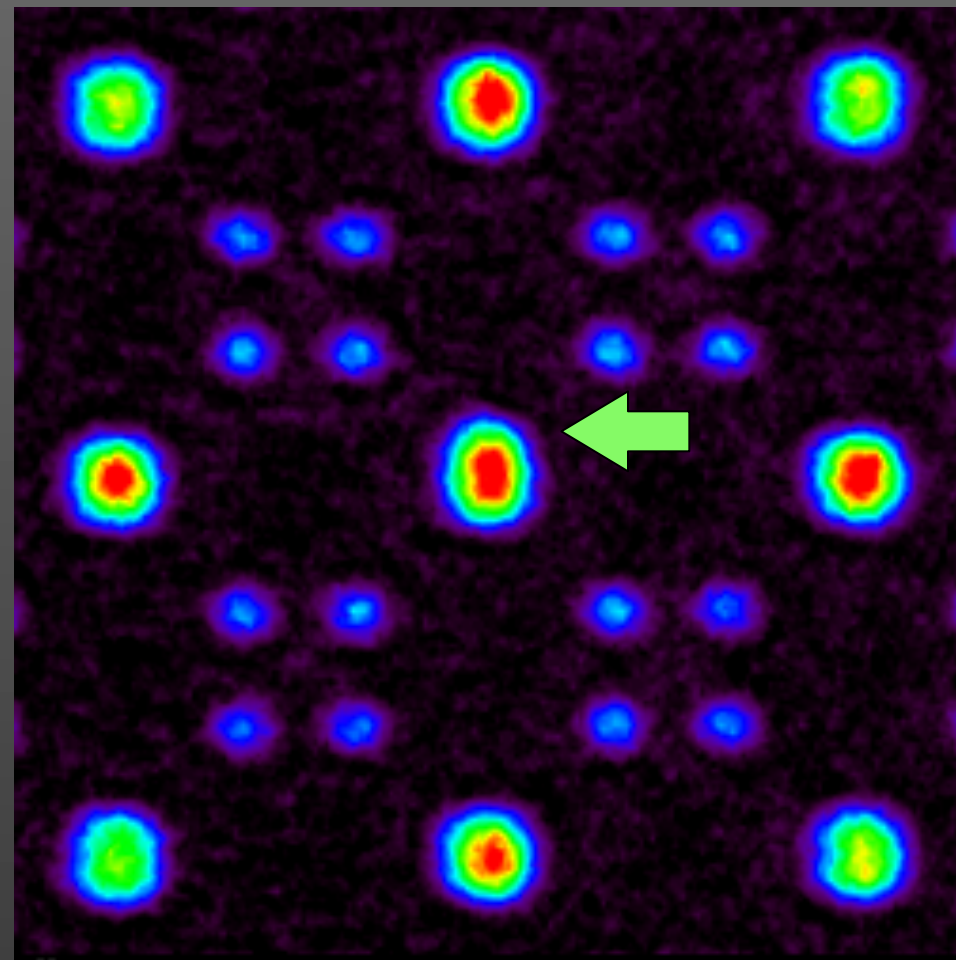


If all you have is a  
microscope, everything  
looks like a defect.

# IBM Programmed Pattern Defects



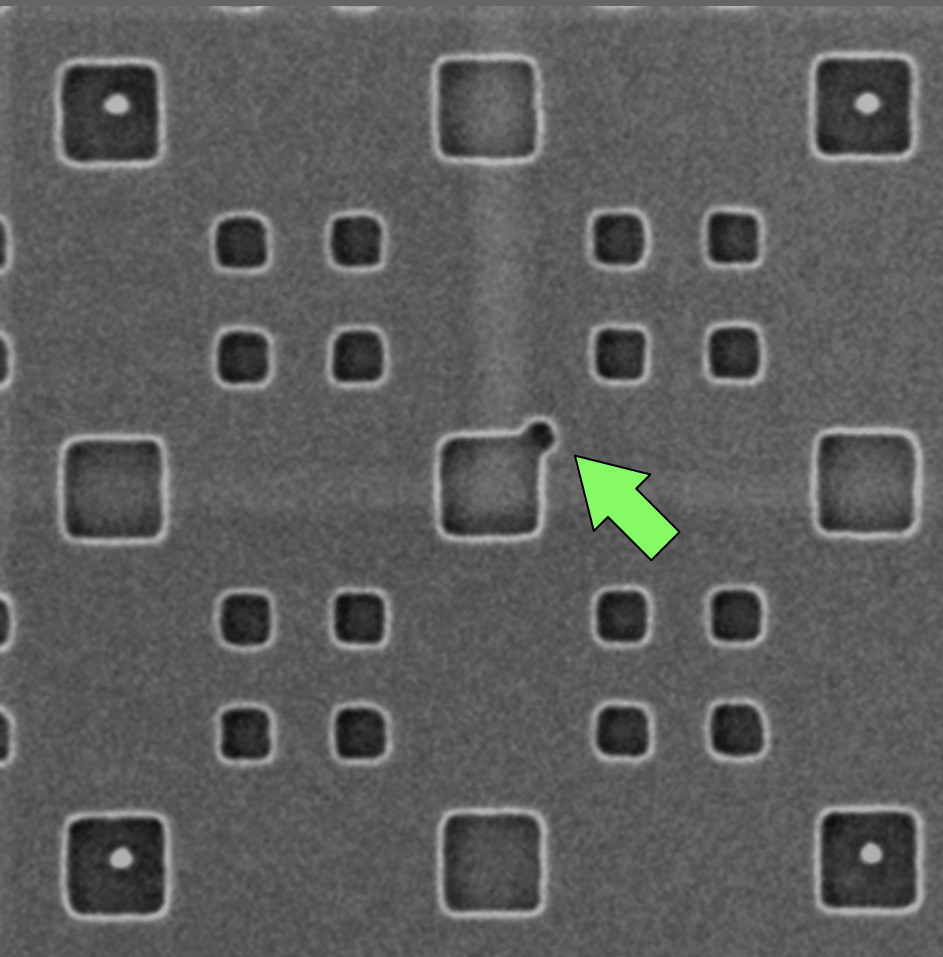
**SEM**



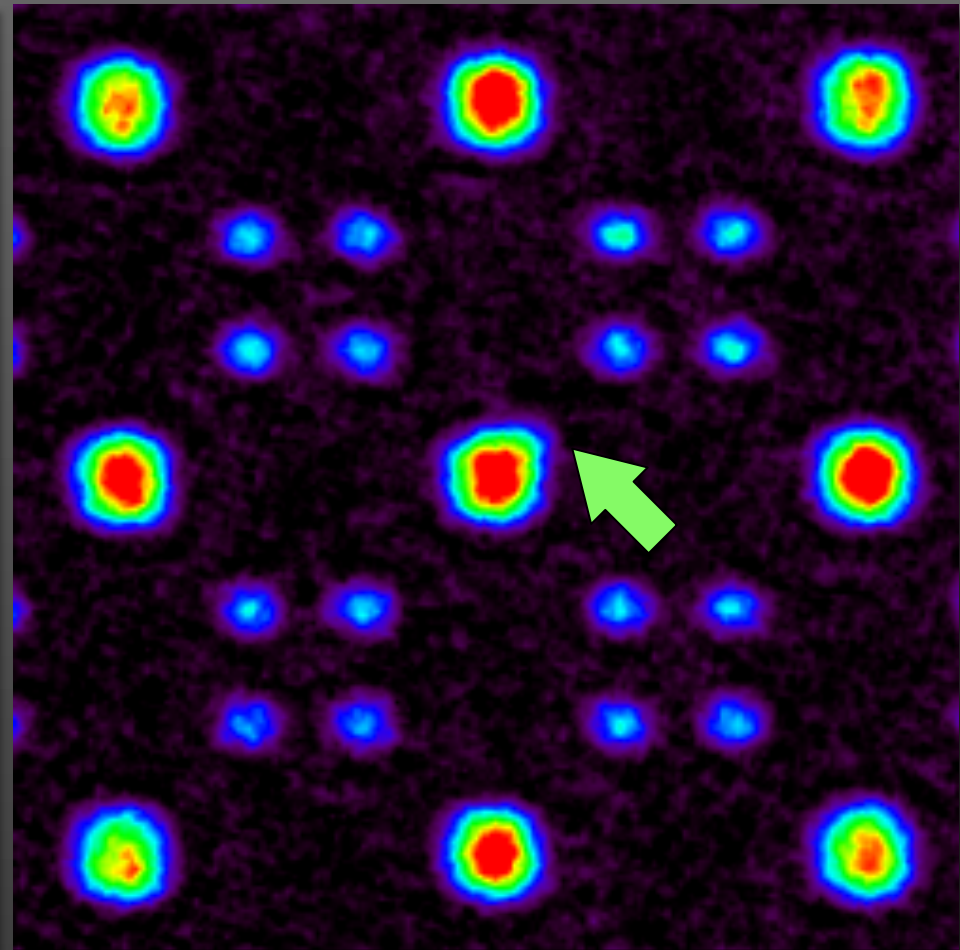
**AIT (EUV)**

**— 500 nm**

# IBM Programmed Pattern Defects



**SEM**



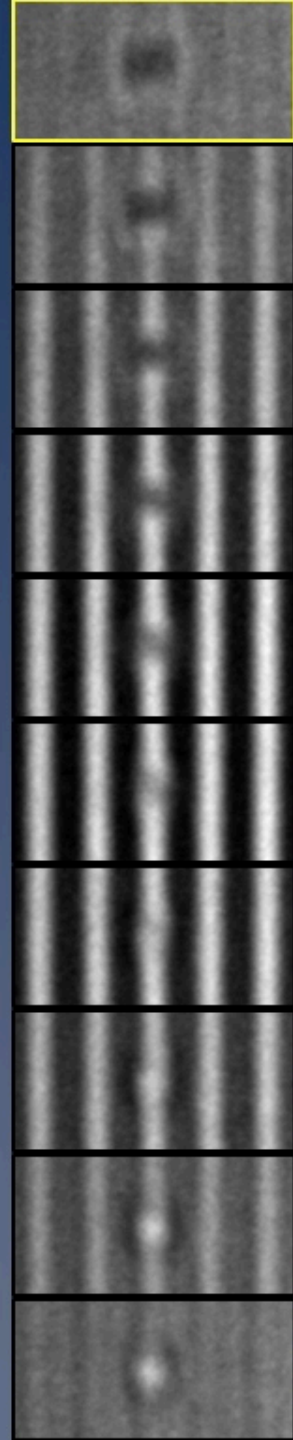
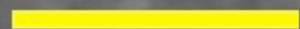
**AIT (EUV)**

**— 500 nm**



# Native Defect Studies

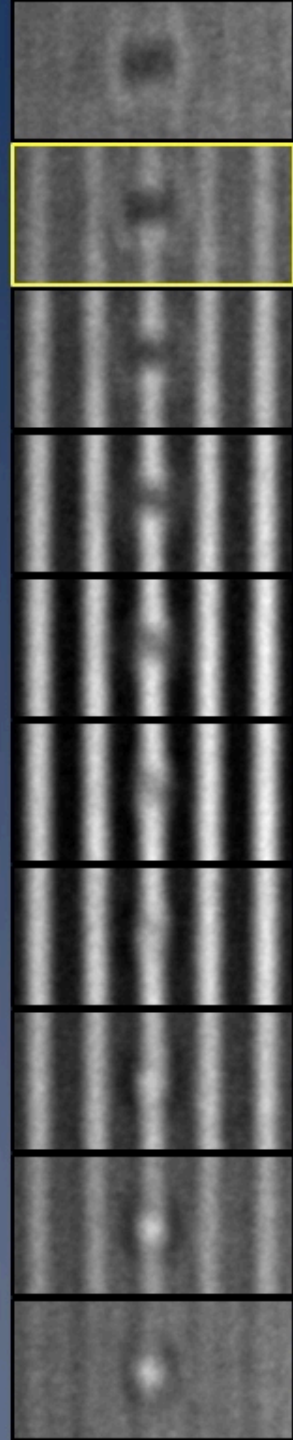
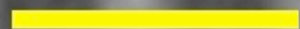
500 nm



Focus

# Native Defect Studies

500 nm

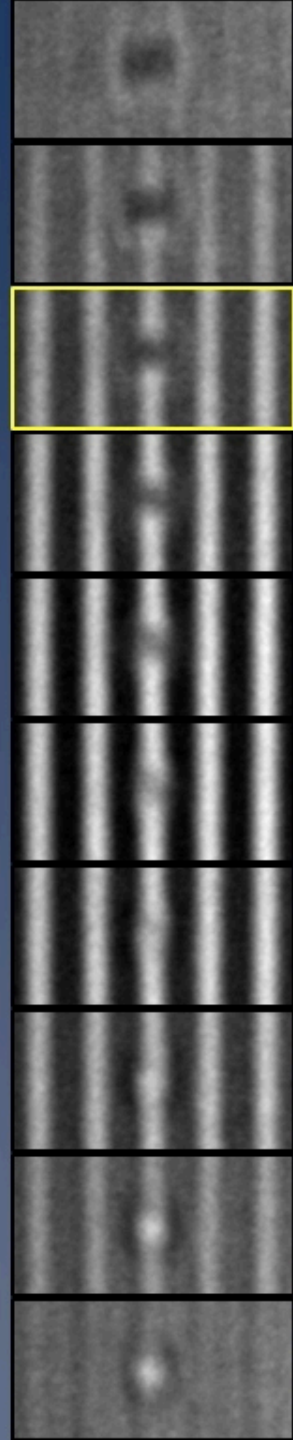


Focus



# Native Defect Studies

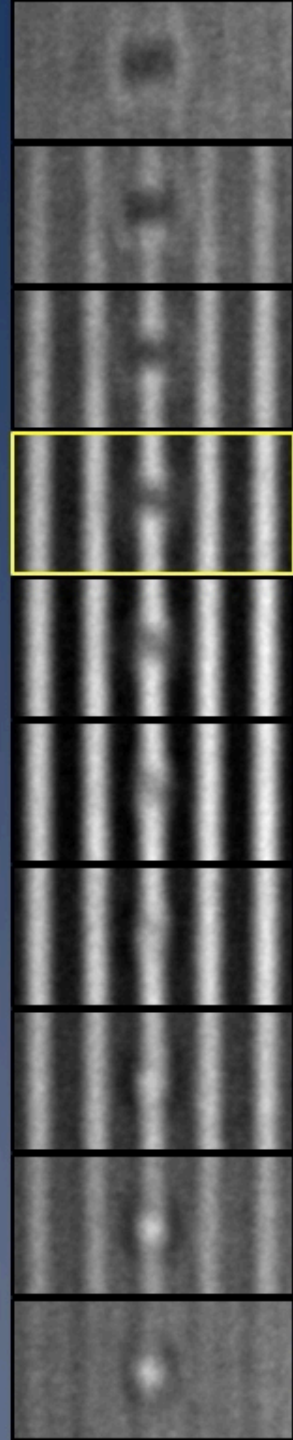
500 nm



Focus

# Native Defect Studies

500 nm

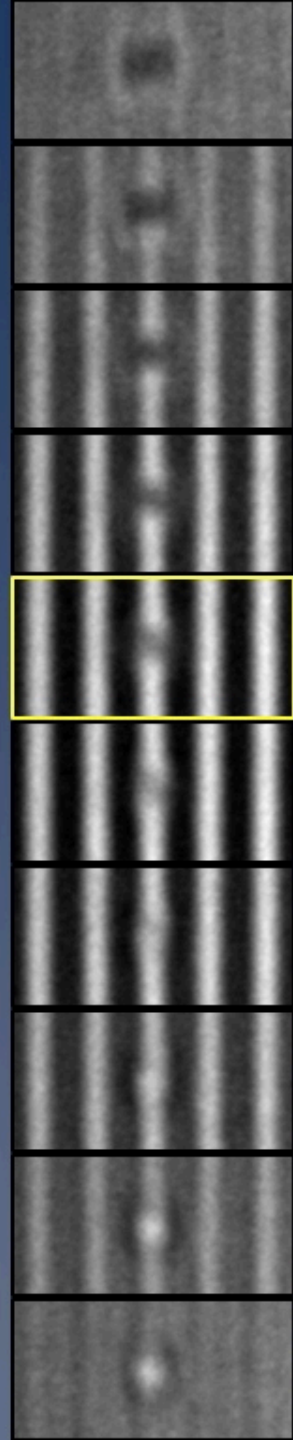


Focus



# Native Defect Studies

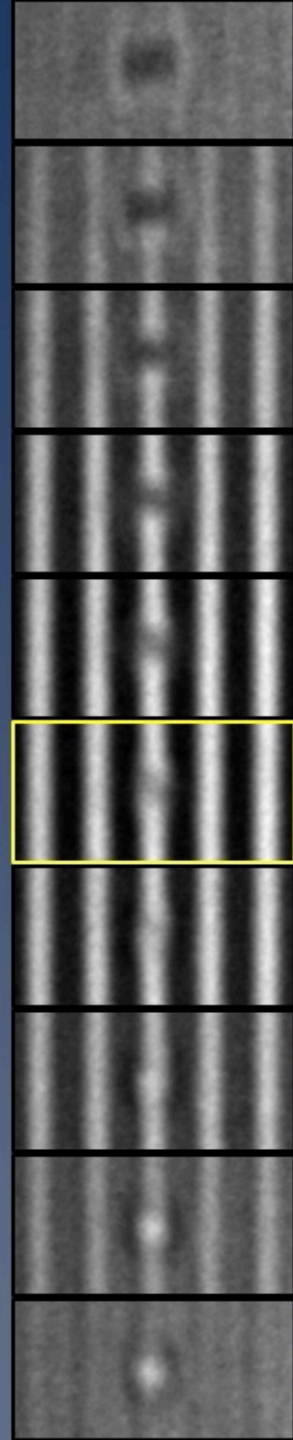
500 nm



Focus

# Native Defect Studies

500 nm

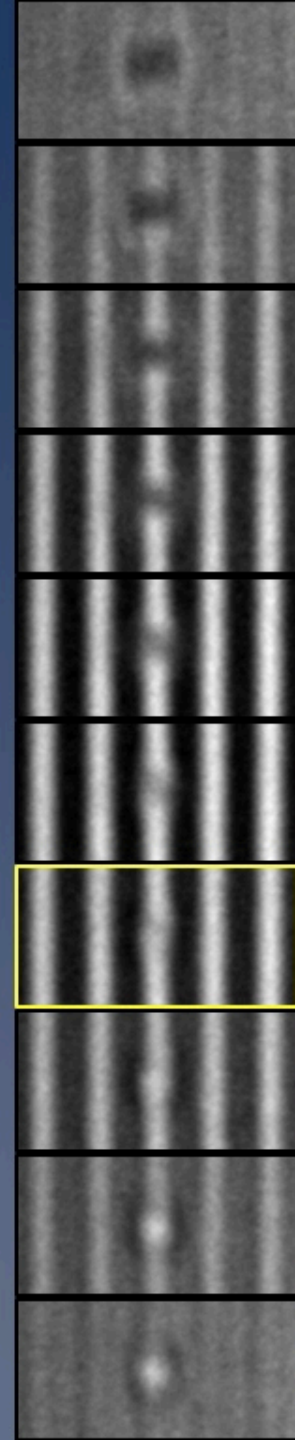


Focus



# Native Defect Studies

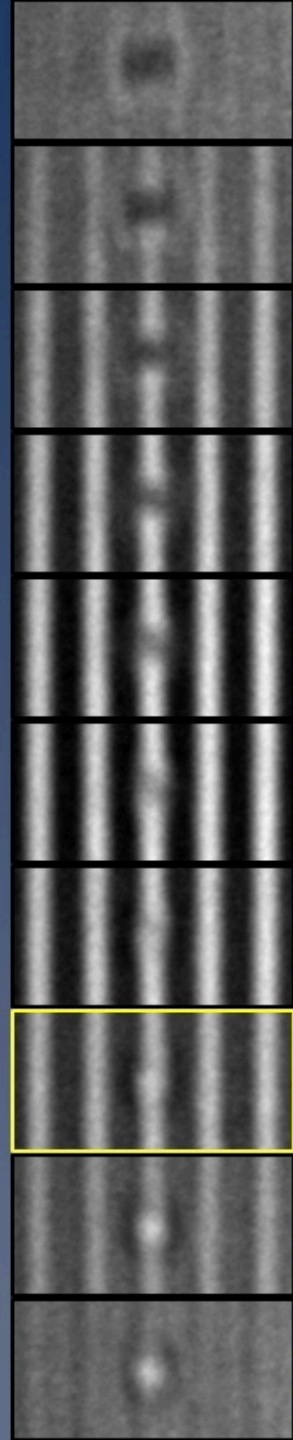
500 nm



Focus

# Native Defect Studies

500 nm

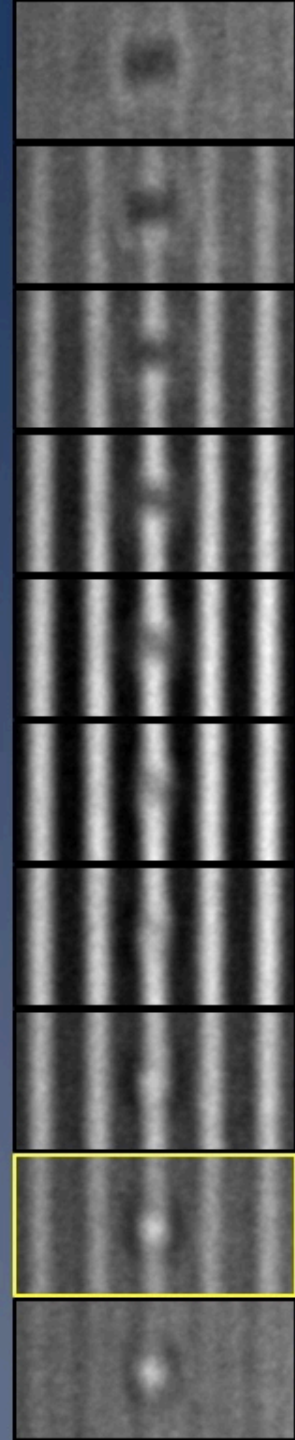
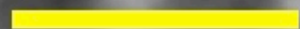


Focus



# Native Defect Studies

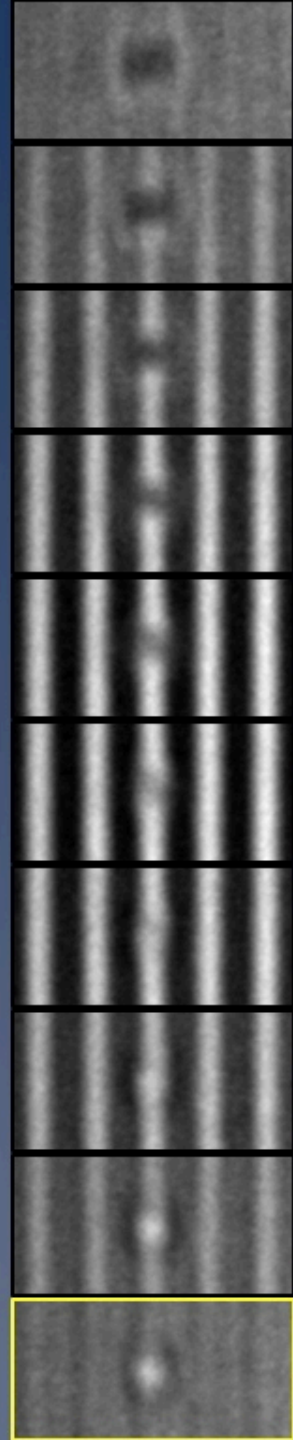
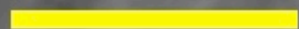
500 nm



Focus

# Native Defect Studies

500 nm



Focus



***PIT***

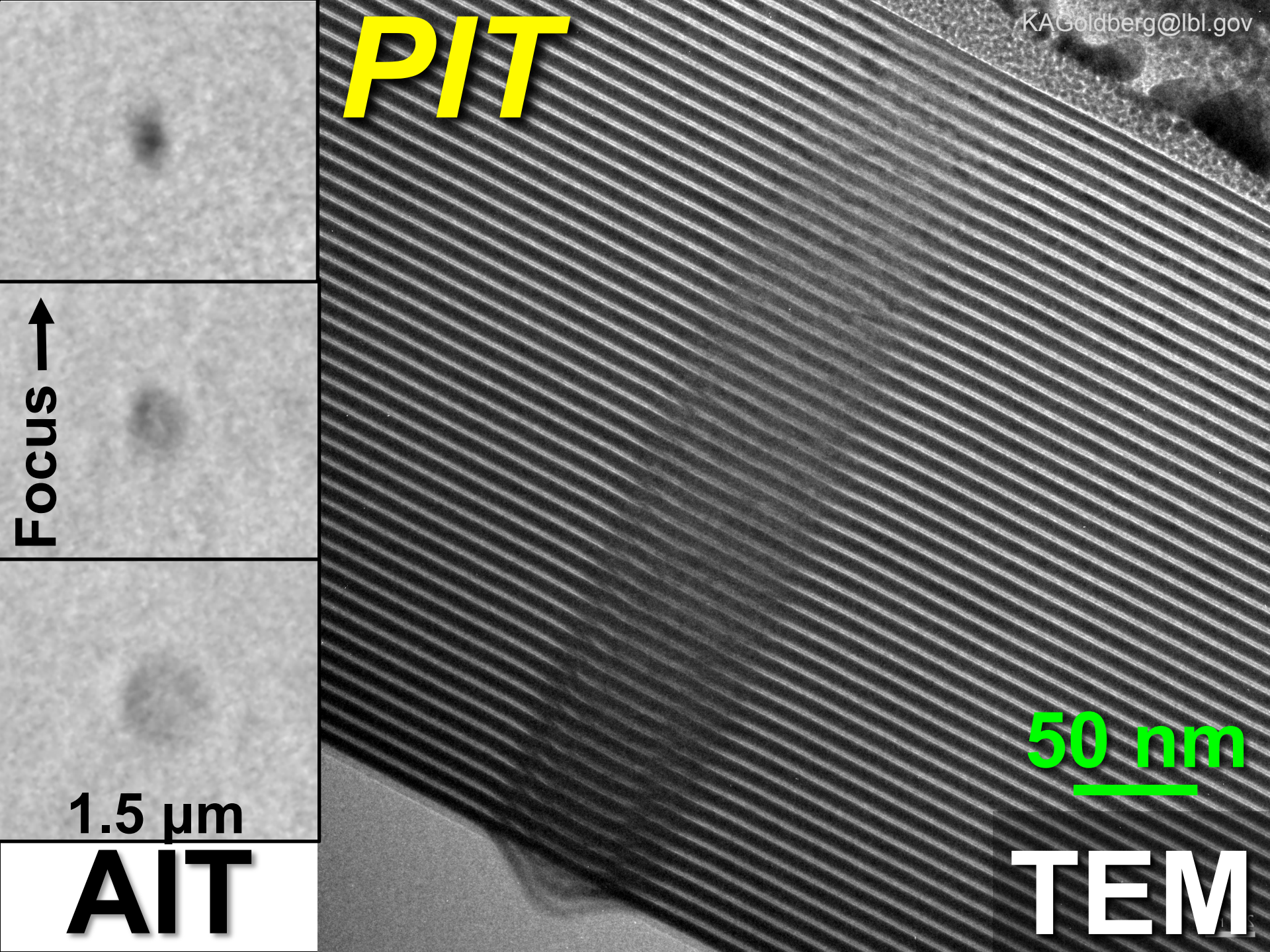
Focus ↑

1.5  $\mu\text{m}$

**AIT**

**50 nm**

**TEM**





***BUMP***

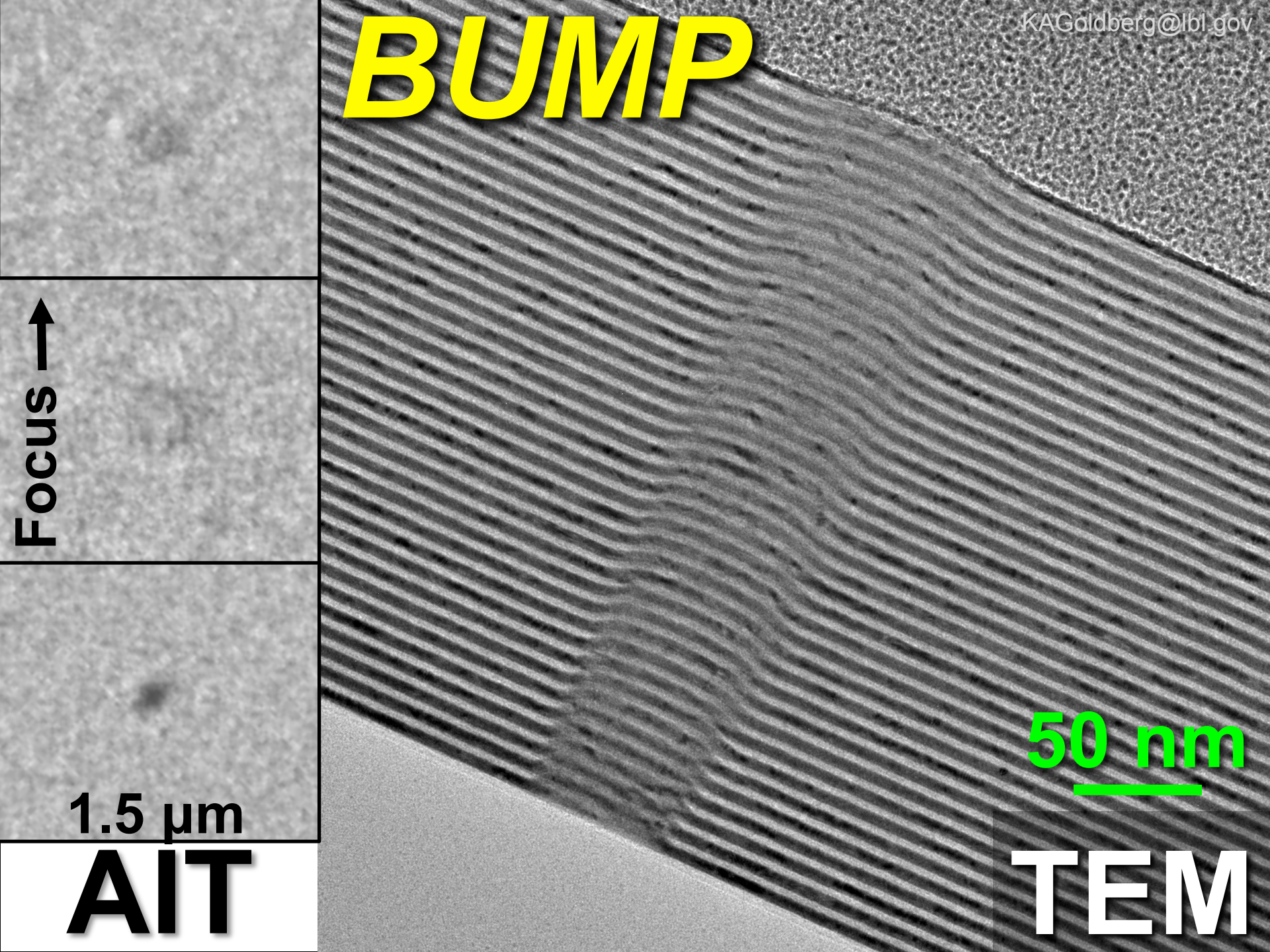
Focus ↑

1.5  $\mu\text{m}$

**AIT**

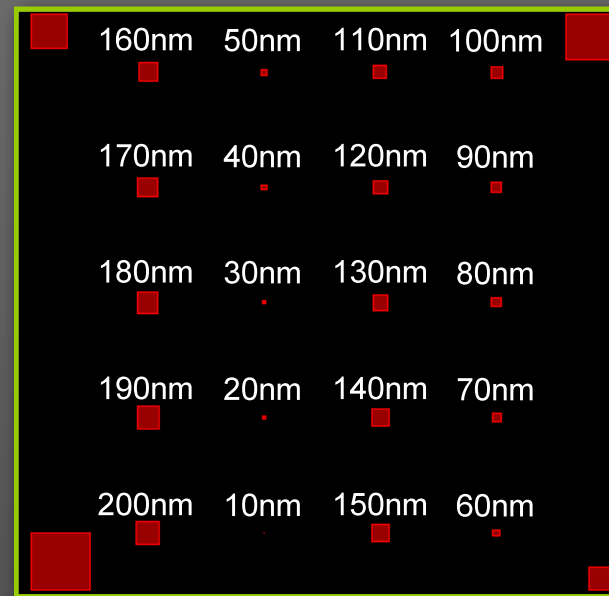
**50 nm**

**TEM**

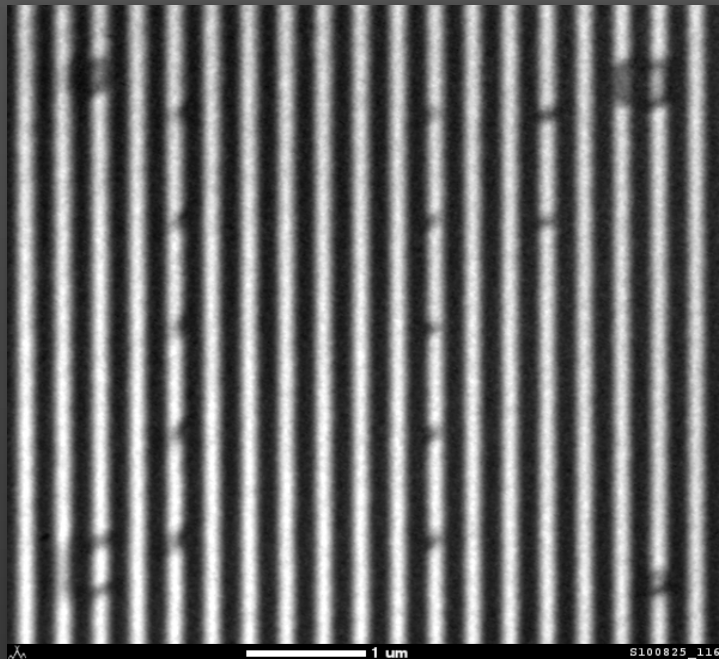




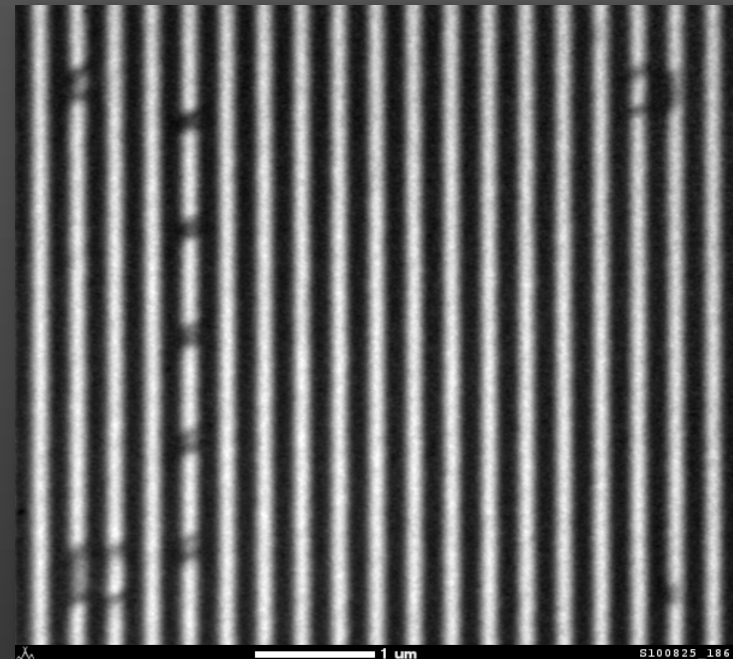
# Buried phase defects



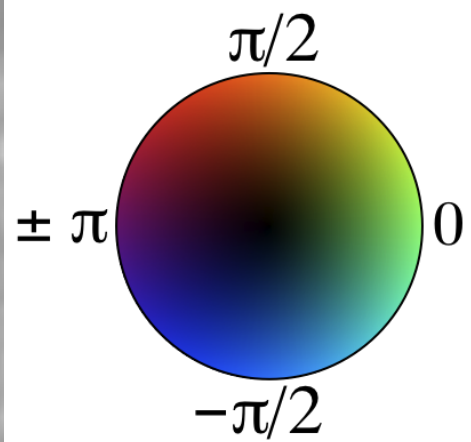
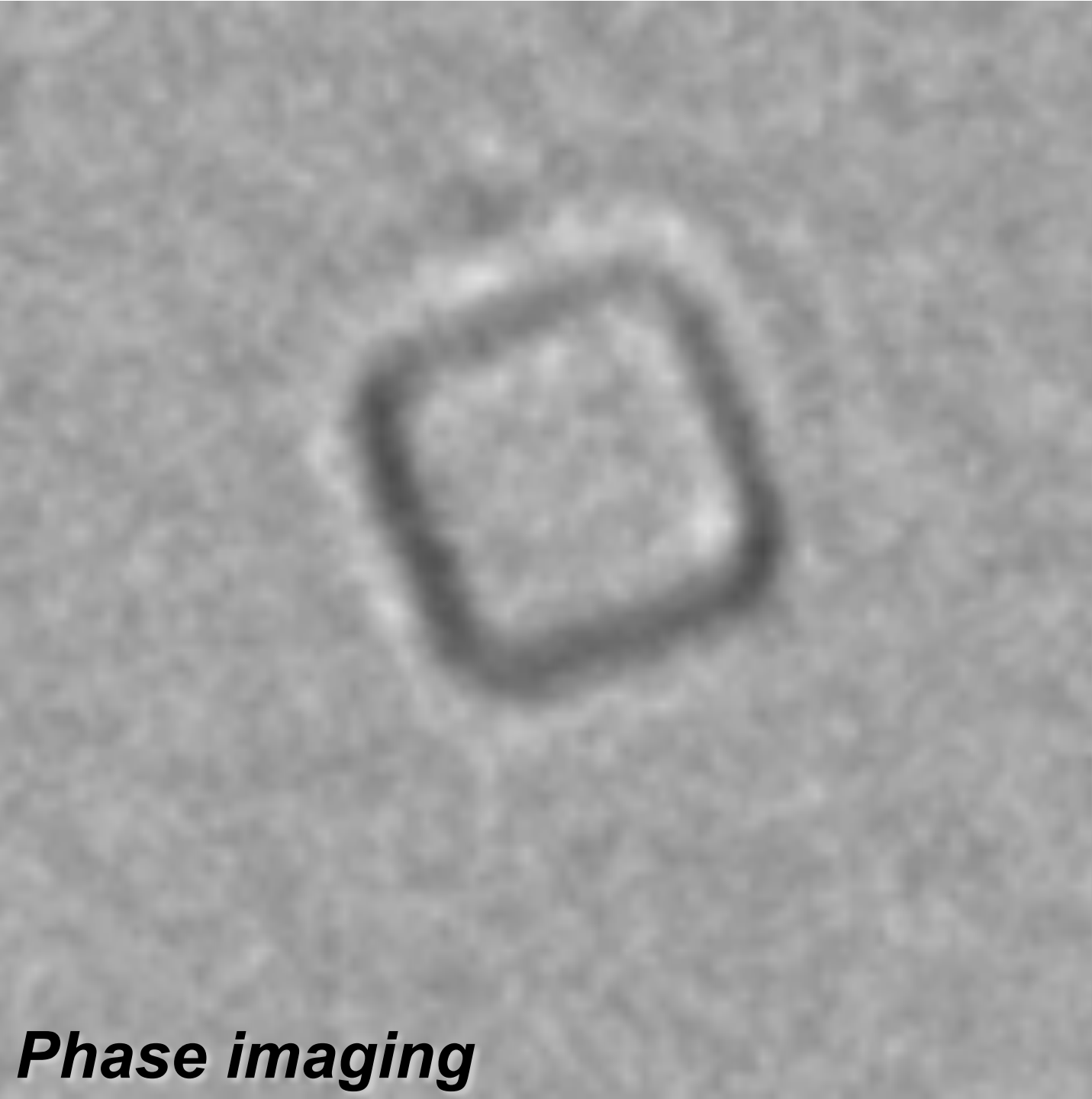
## AIT Images



A pattern position shift. . .

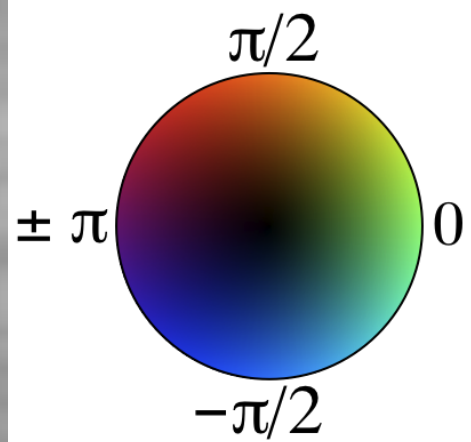
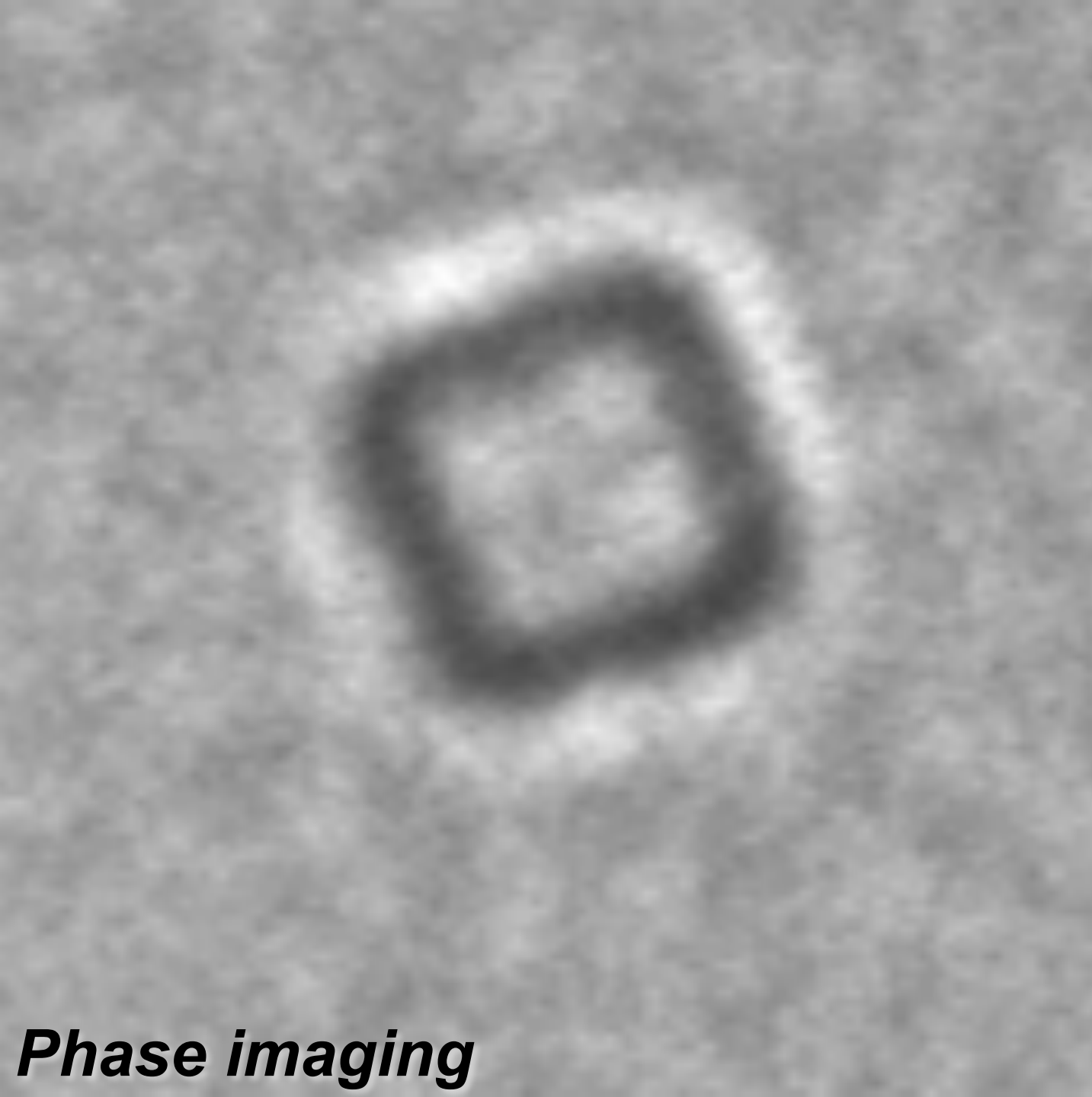


covers the defects



**$0.5 \mu\text{m}$**

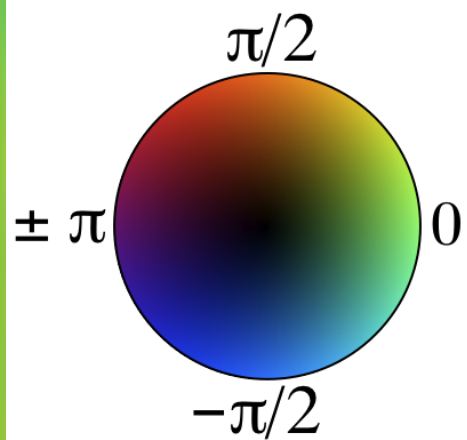
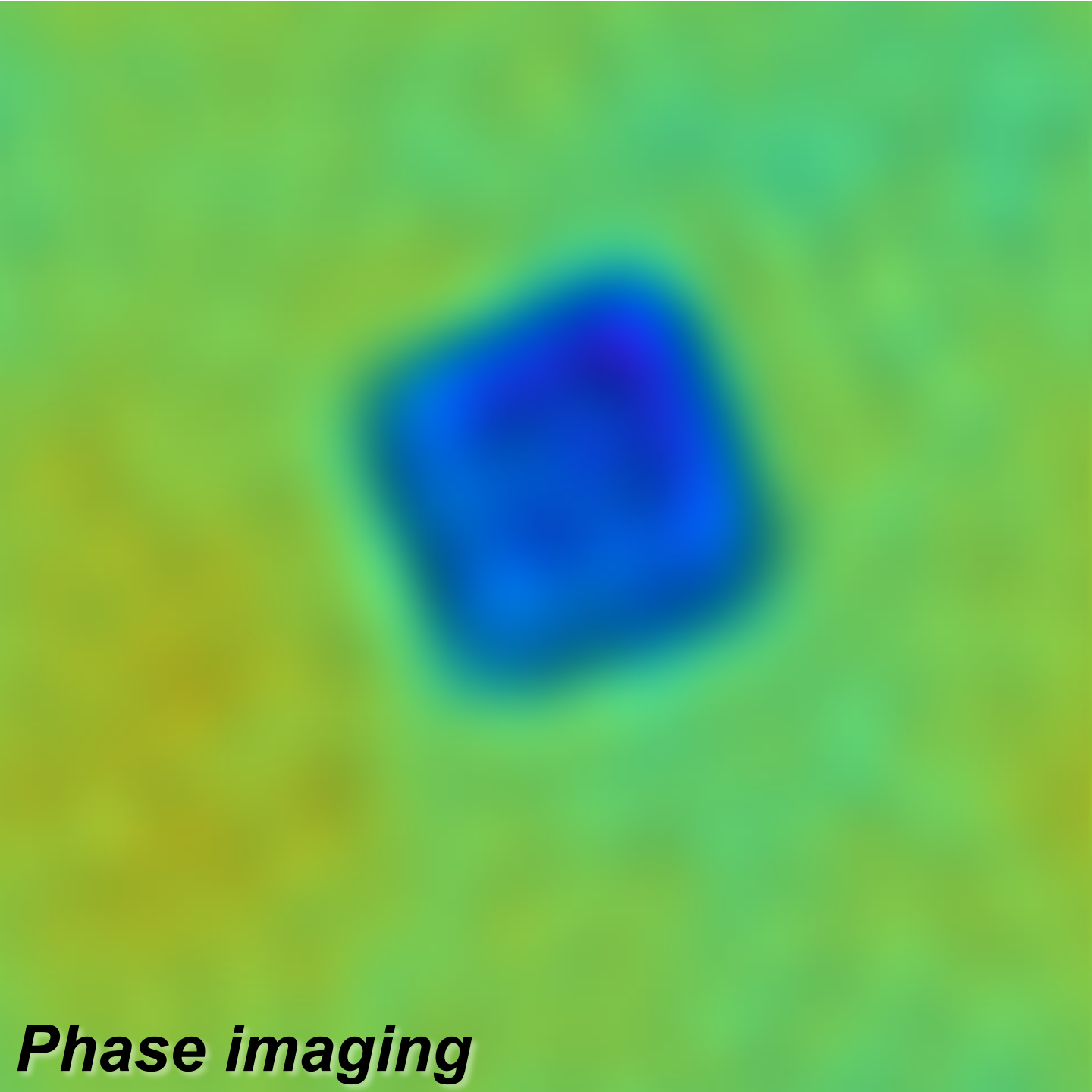
***Phase imaging***



**$0.5 \mu\text{m}$**

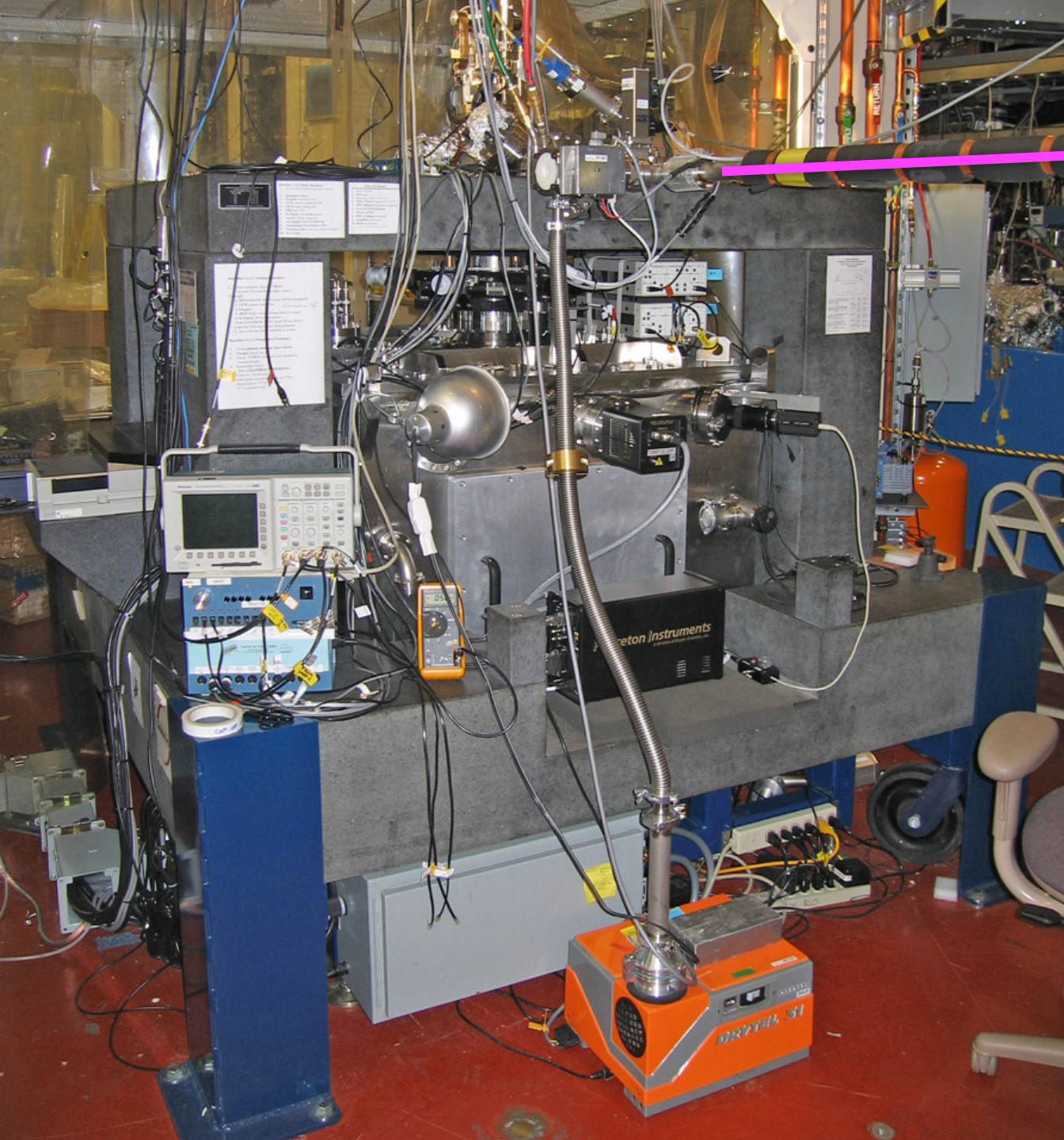
***Phase imaging***





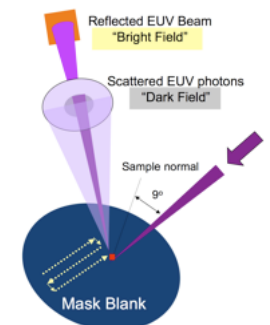
**$0.5 \mu\text{m}$**

***Phase imaging***

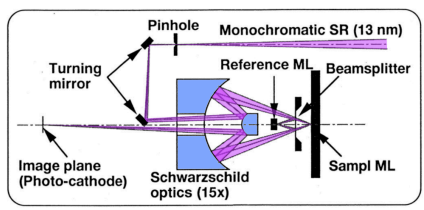


**The AIT**

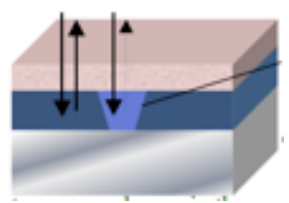
# 14+ years of actinic mask inspection/imaging



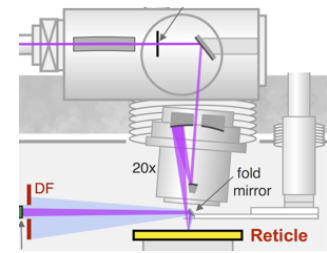
**EUV LLC/LBNL**



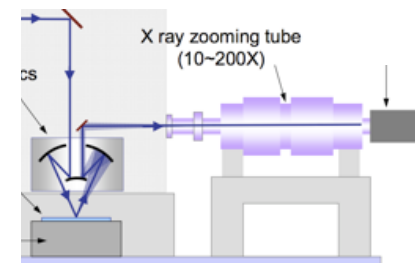
**NTT**



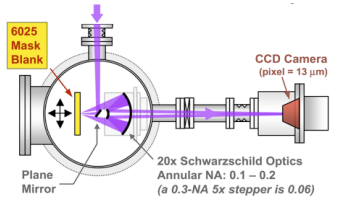
**Lucent**



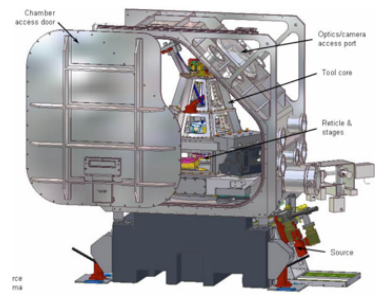
**SEMATECH/LBNL**



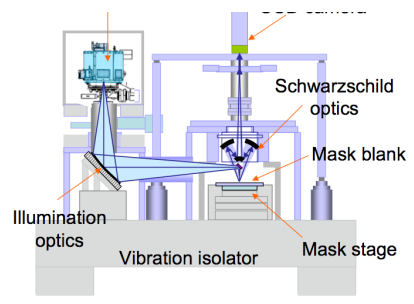
**U. Hyogo**



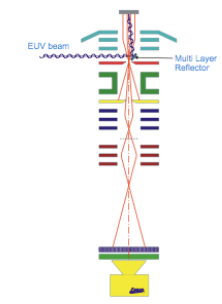
**MIRAI**



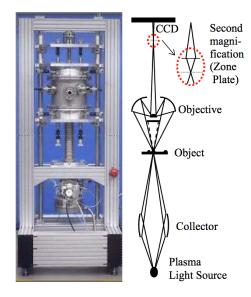
**Exitech**



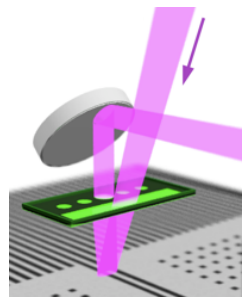
**MIRAI II/Selete**



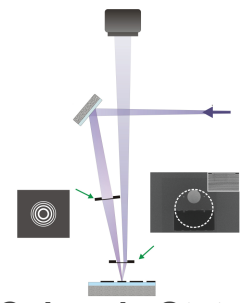
**U. Bielefeld**



**Fraunhofer Institute**



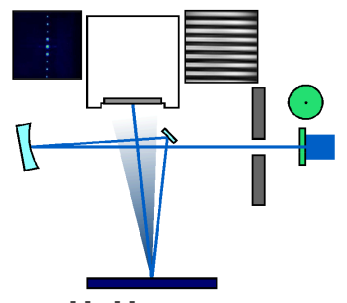
**SEMATECH/LBNL**



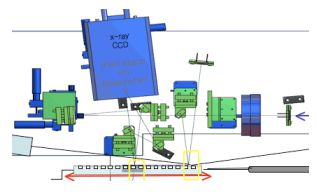
**Colorado State**



**INVENT/CNSE**



**U. Hyogo**



**Hanyang**



**Zeiss future**



## **EFFICIENT**

- lots of data per shift

## **COHERENCE CONTROL**

emulate all kinds of tools

## **FLEXIBLE**

lots of optical settings

EFFICIENT

l

ift

CO

em

**STABLE!**

DL

tools

FLEX

lots of optical settings

**Source:** Synchrotron

**Optics:** Zoneplate-lenses

**4×NA:** 0.25–0.625

**$\sigma$ :** Programmable

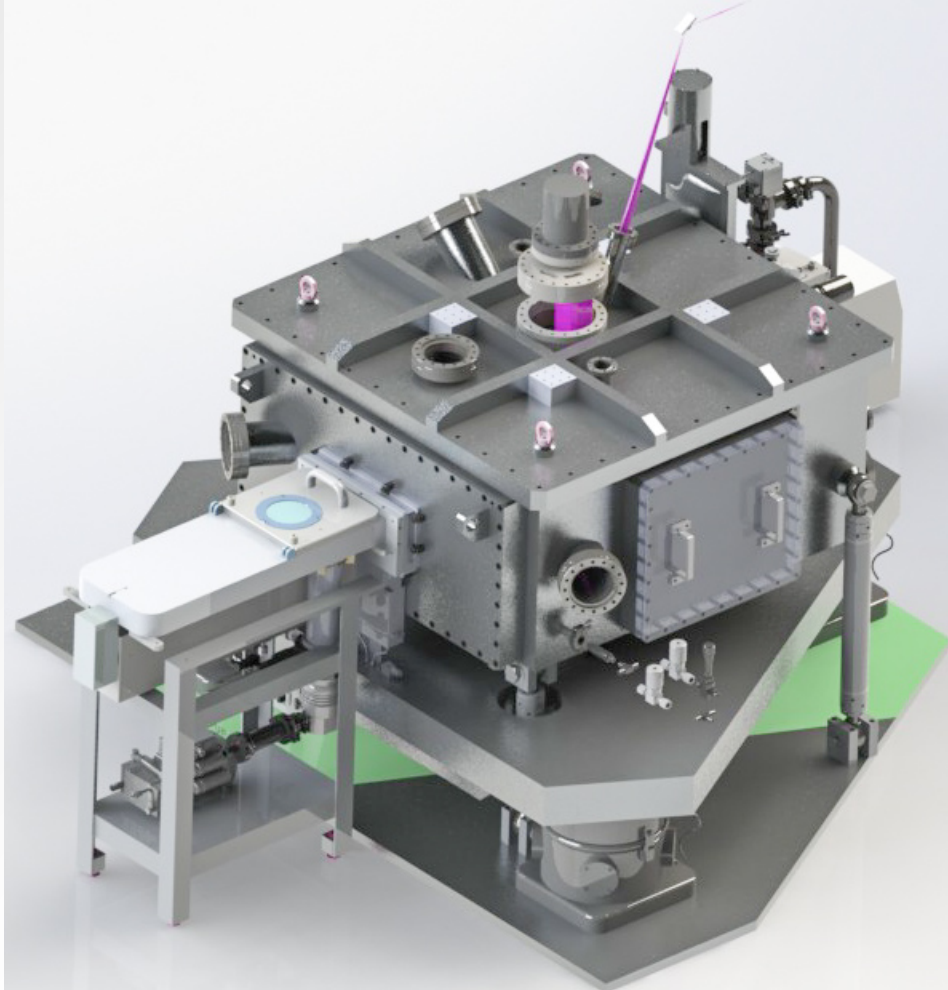
**Nav:** Full-mask xy

**Speed:** 5–10 series/hr

***Vibration Isolation***

# SHARP

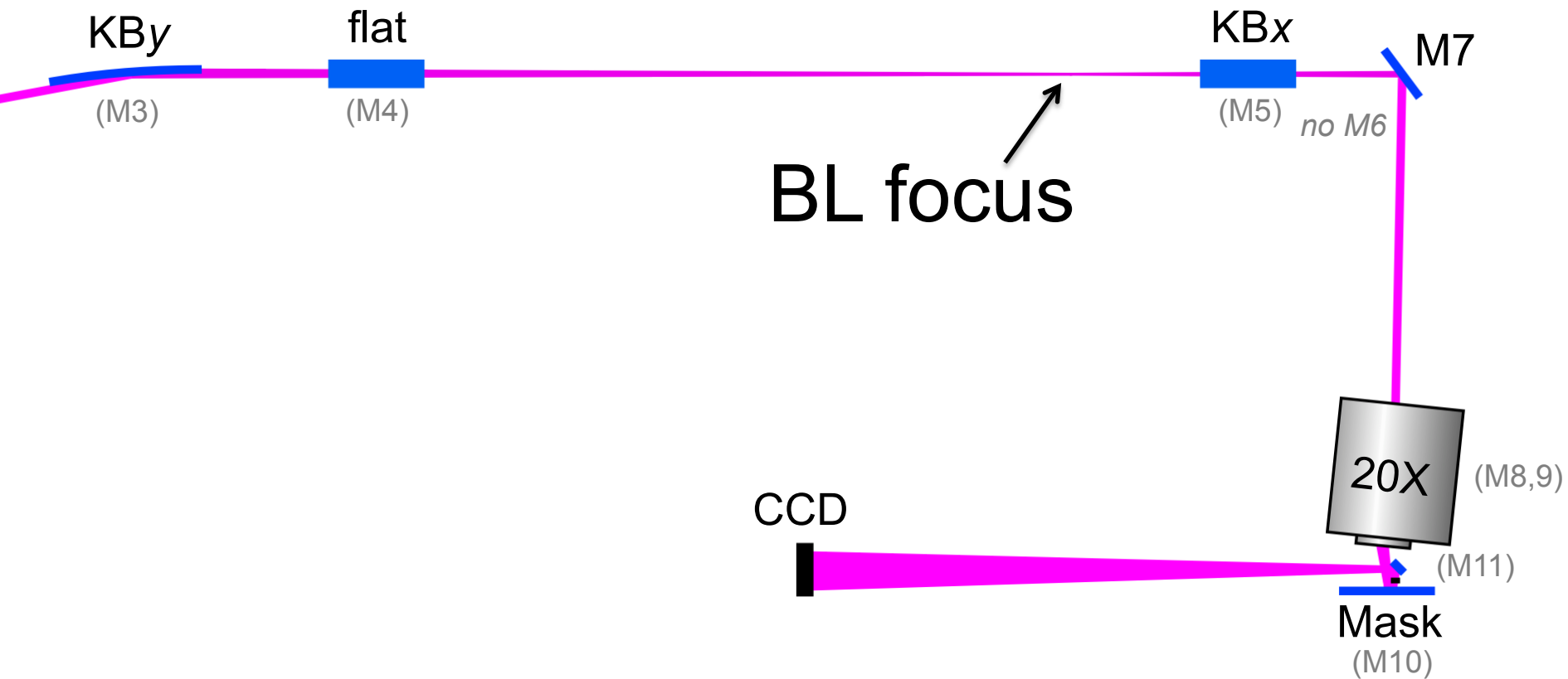
SEMATECH HIGH-NA ACTINIC  
RETICLE REVIEW PROJECT





# POWER





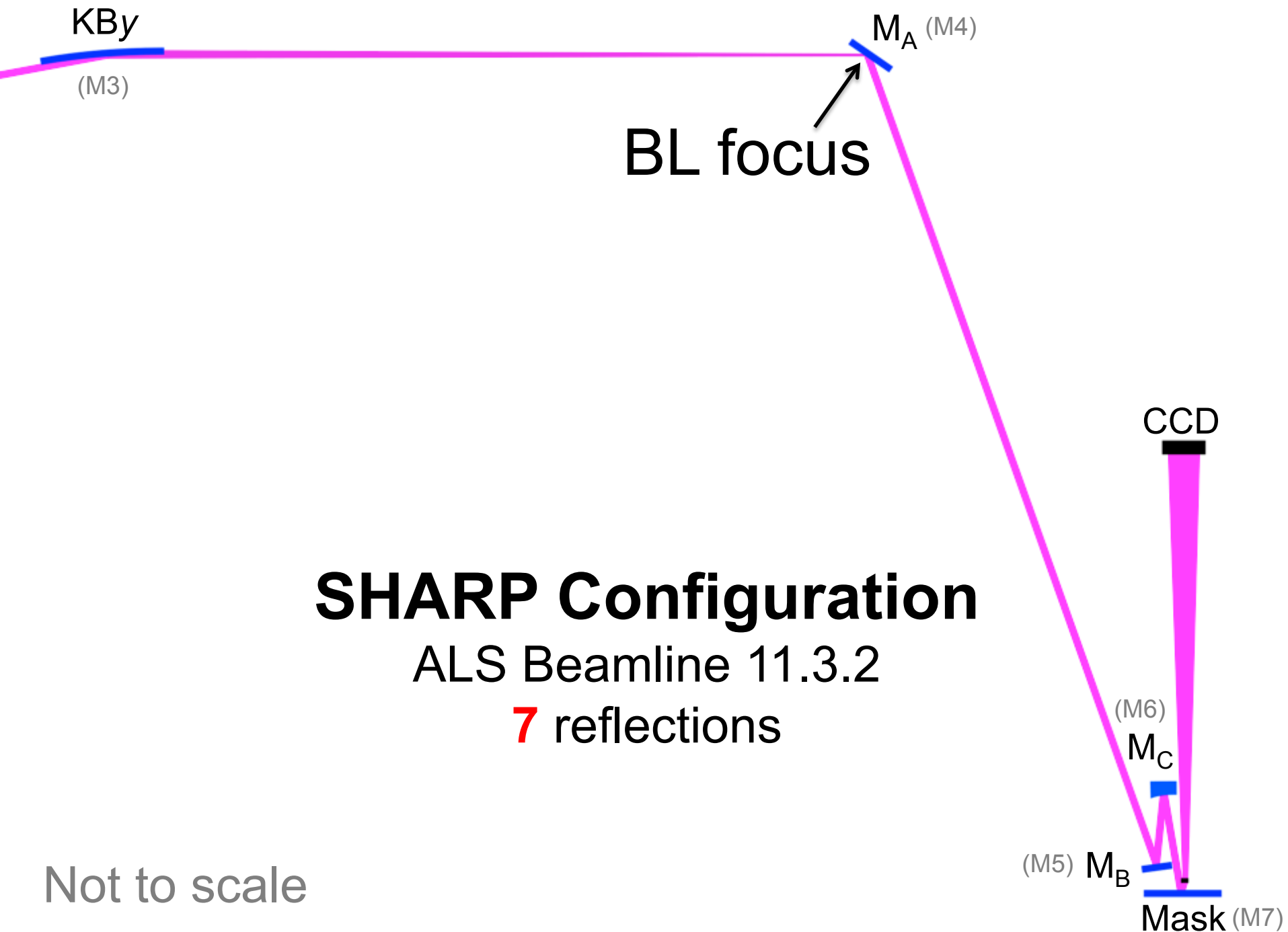
# AIT Configuration

ALS Beamline 11.3.2

**10** reflections

Not to scale

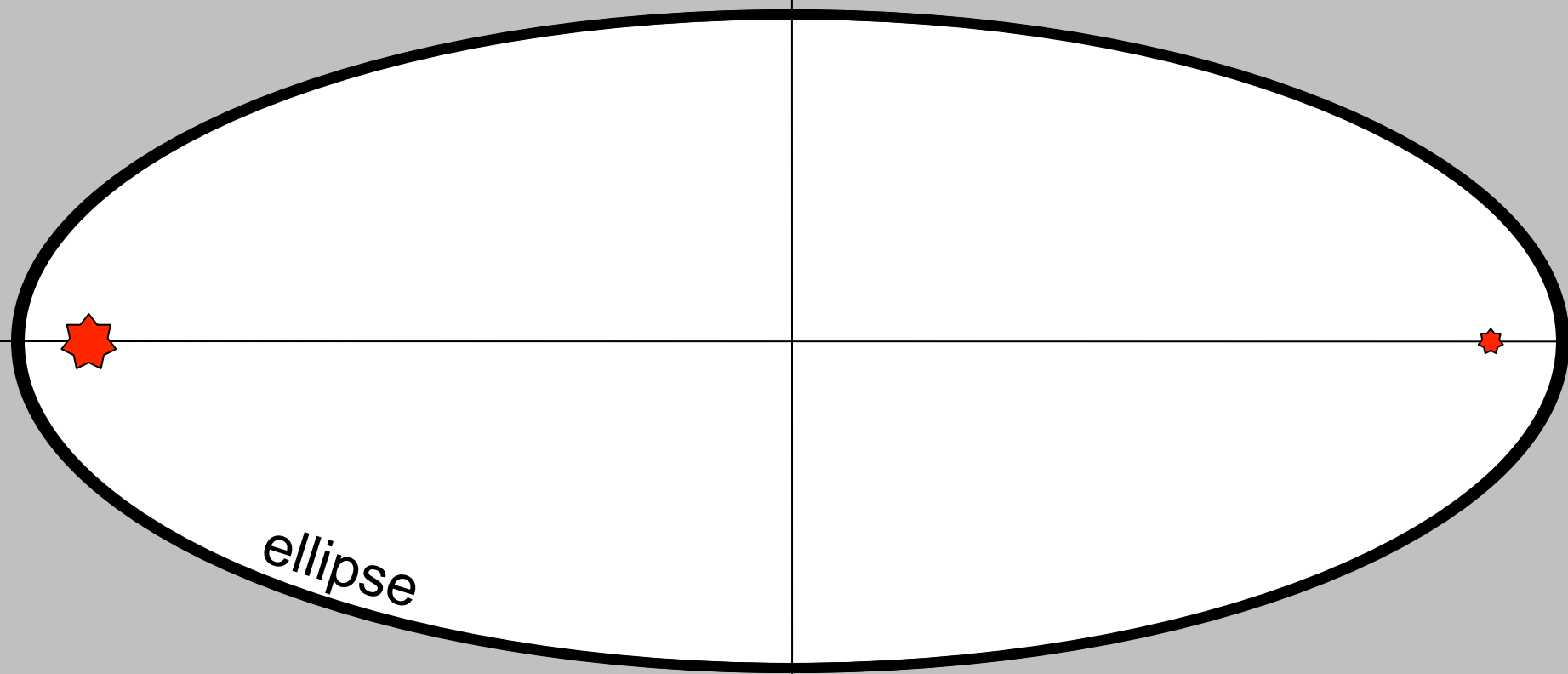




Beamline  
Focus  
250×250 μm

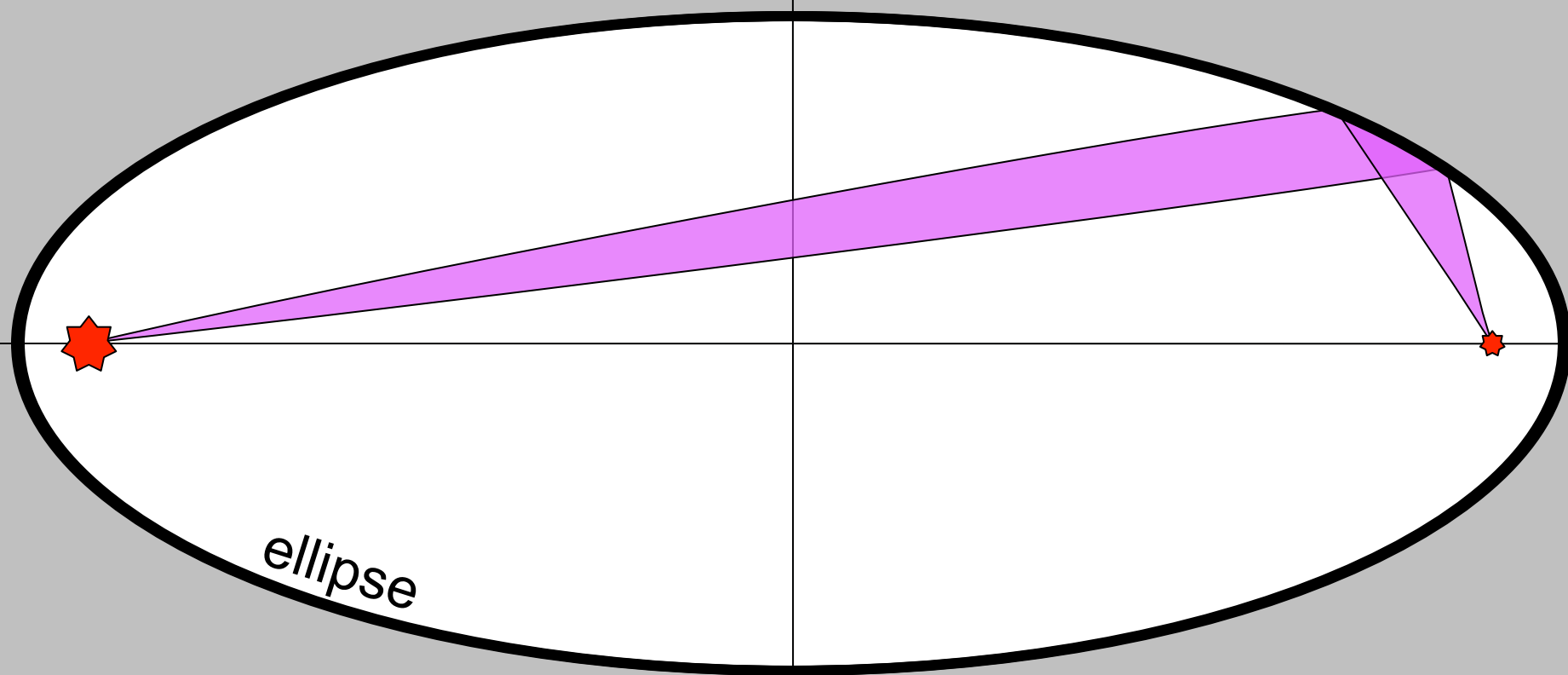
Mask  
Illumination  
Goal 25×25 μm

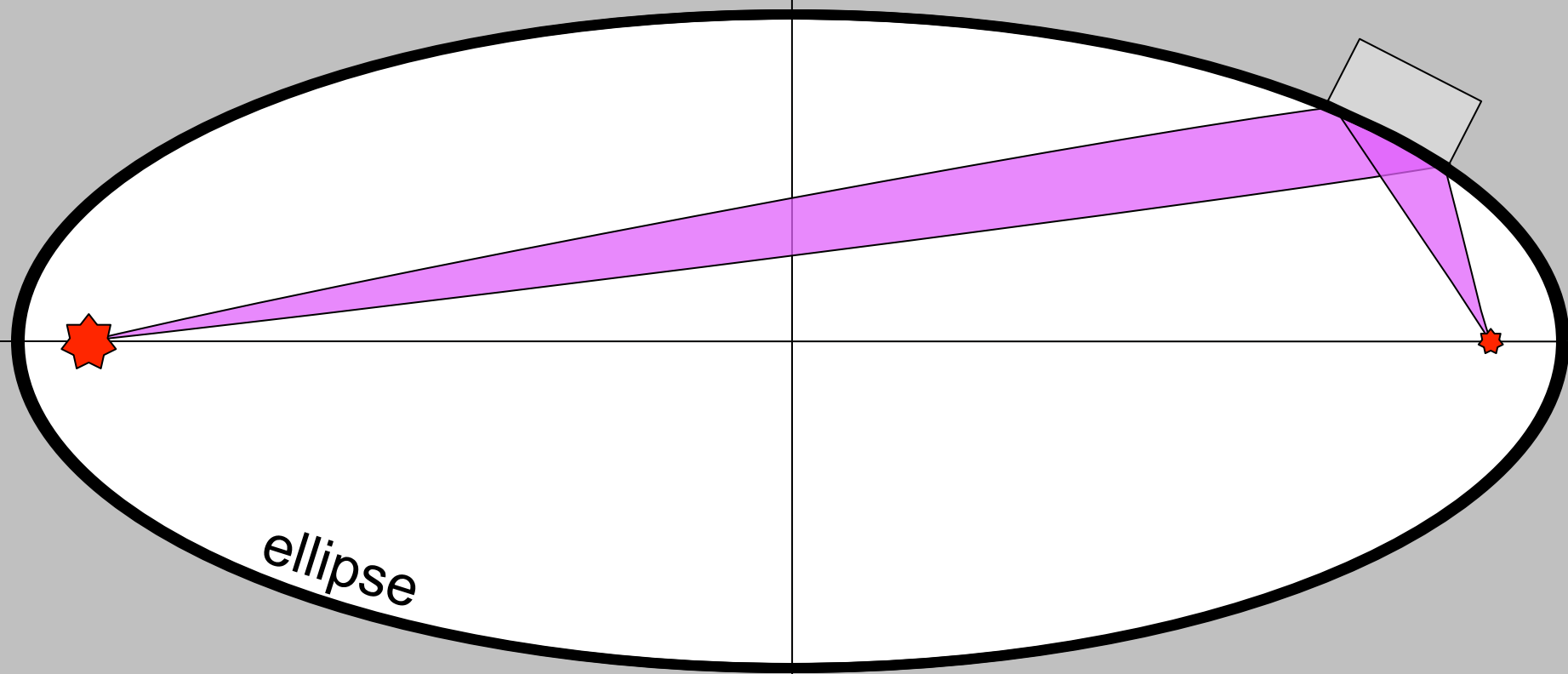


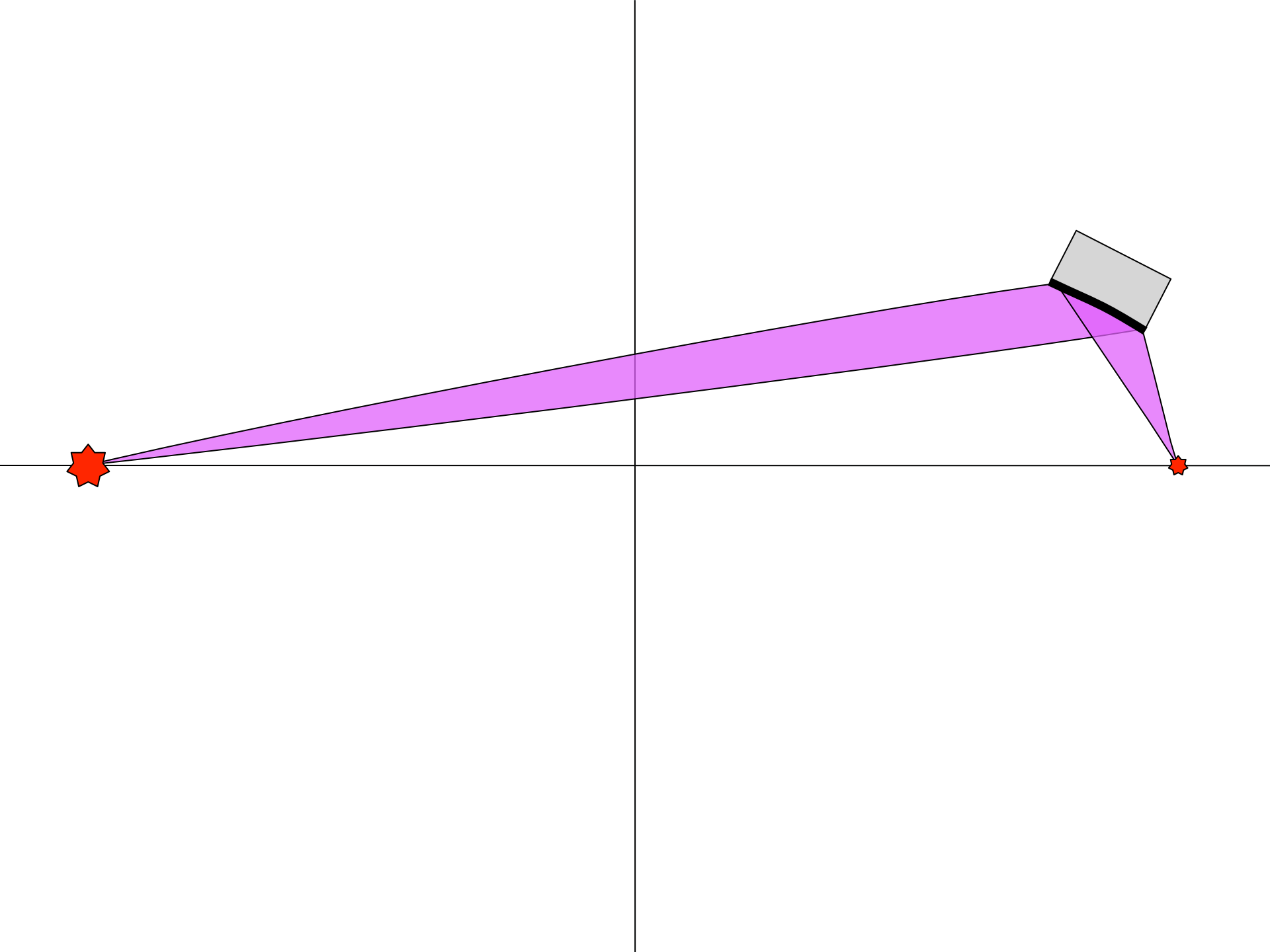


ellipse



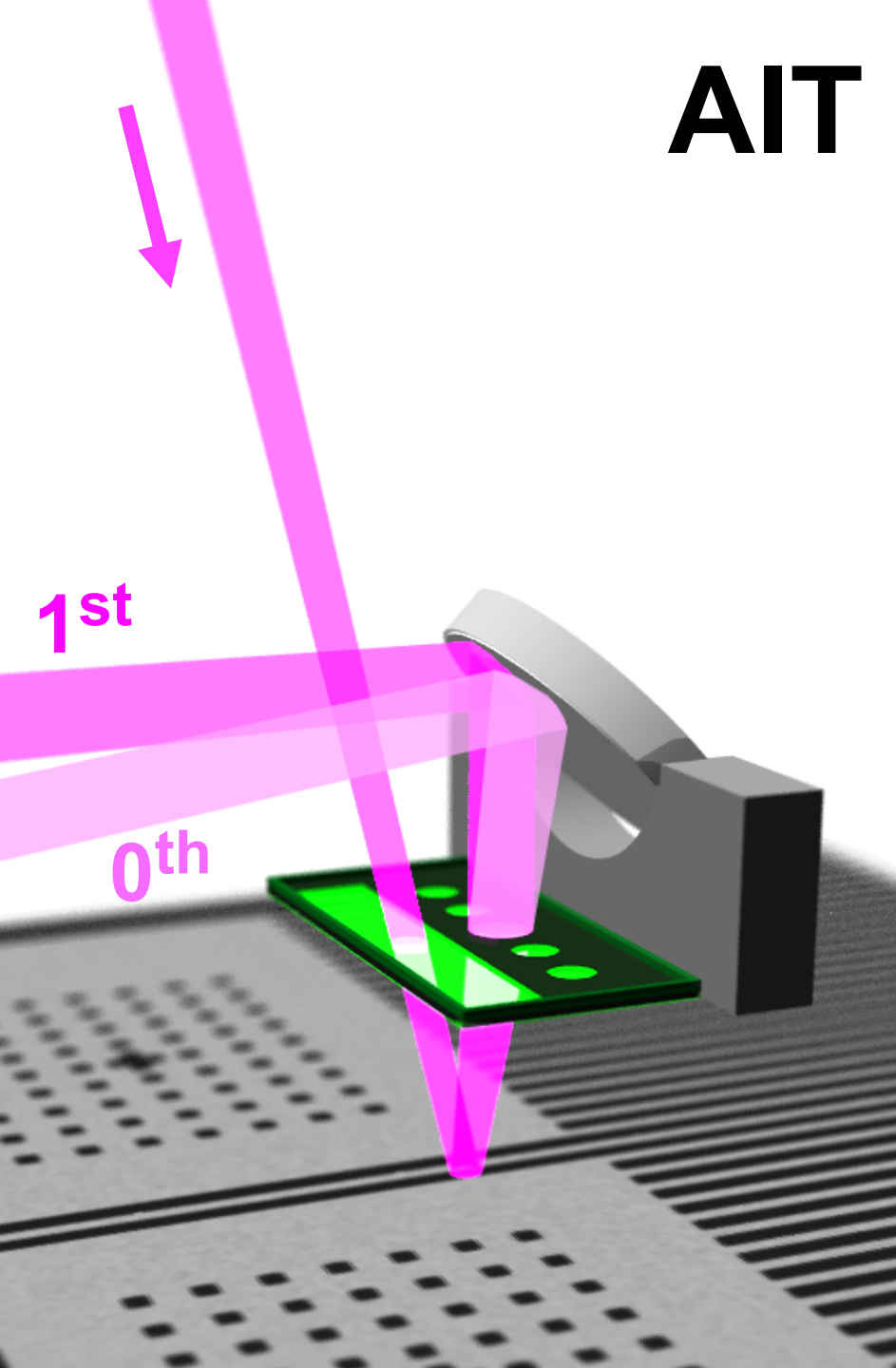




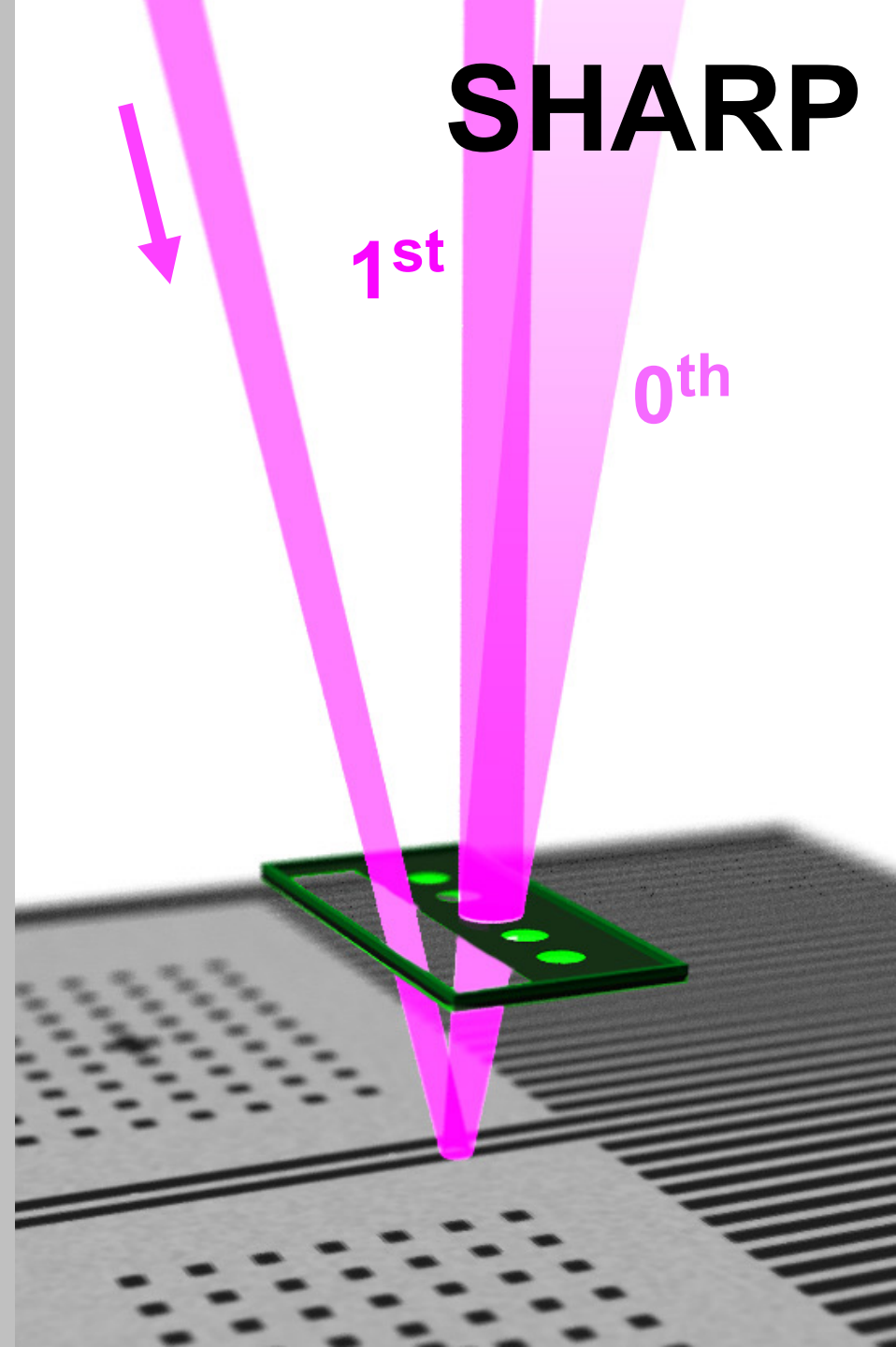




# AIT

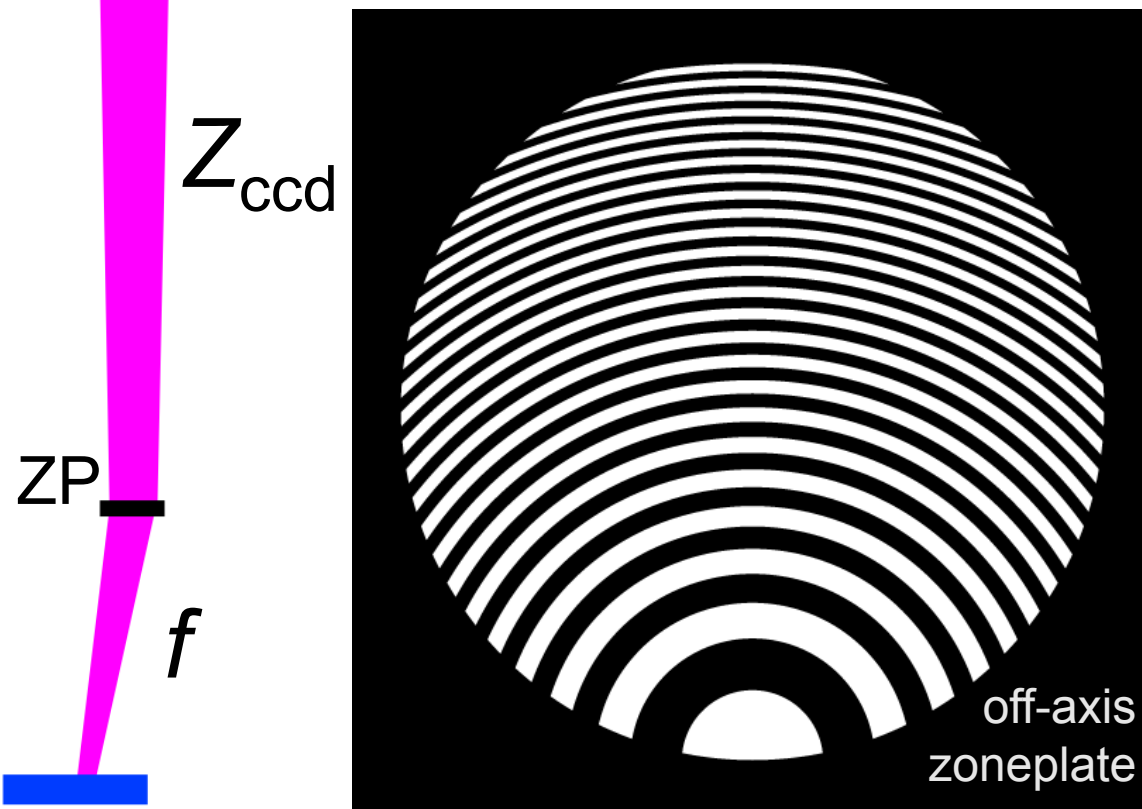


# SHARP



CCD

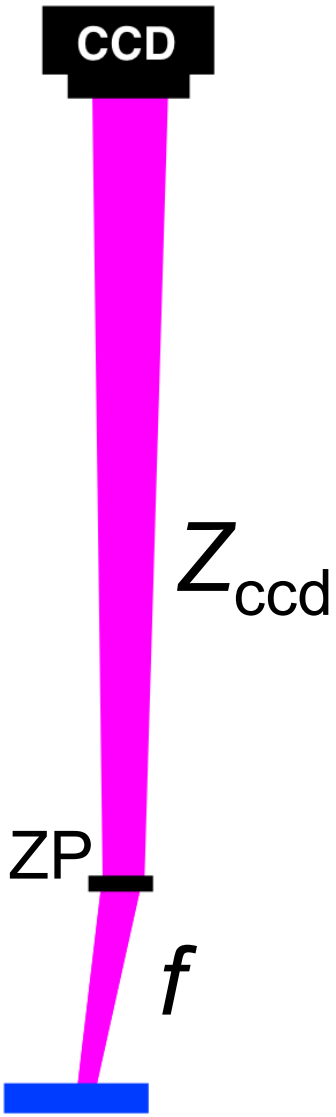
Intensity  $\sim$  Bandwidth / Mag<sup>2</sup>



**Intensity  $\sim$  Bandwidth /  $\text{Mag}^2$**

$$\text{Mag} = Z_{\text{ccd}} / f$$

$$\text{Bandwidth} \sim 1/N_{\text{zones}} \sim 1/f$$



$$\text{Intensity} \sim 1/f$$

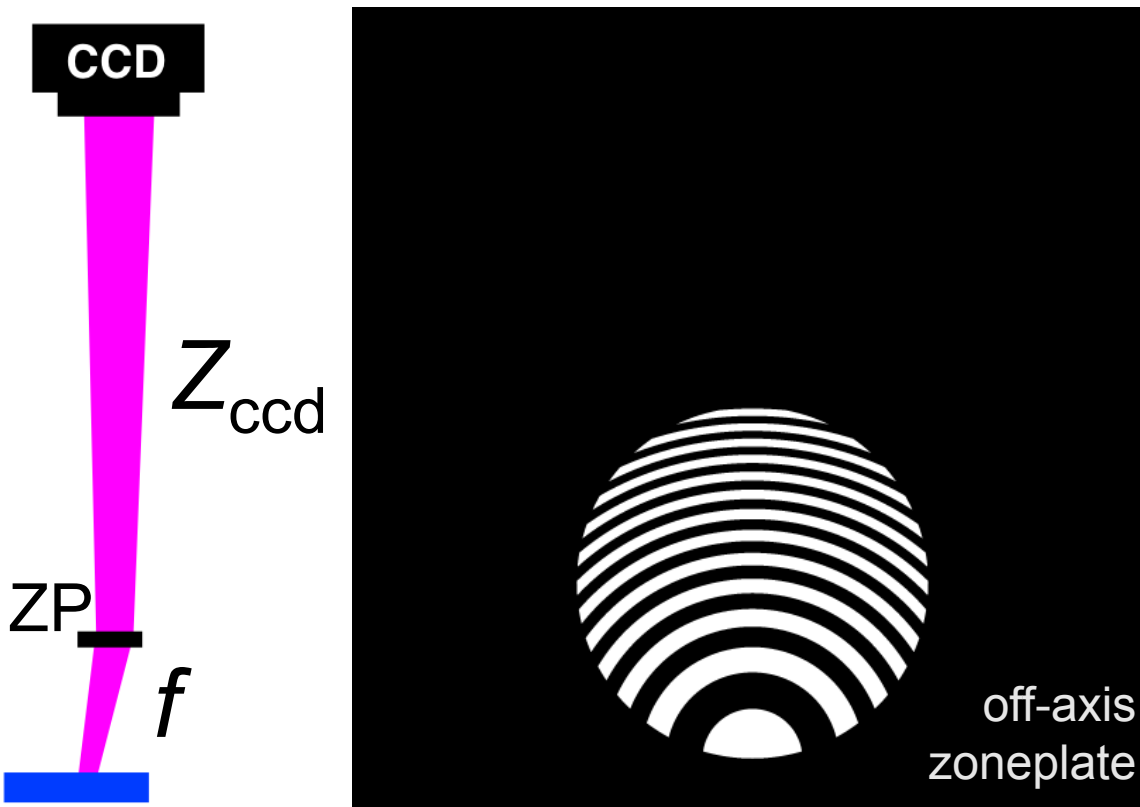
We want  $f =$   
 $750 \rightarrow 500 \rightarrow 250 \mu\text{m}$



**Intensity  $\sim$  Bandwidth /  $\text{Mag}^2$**

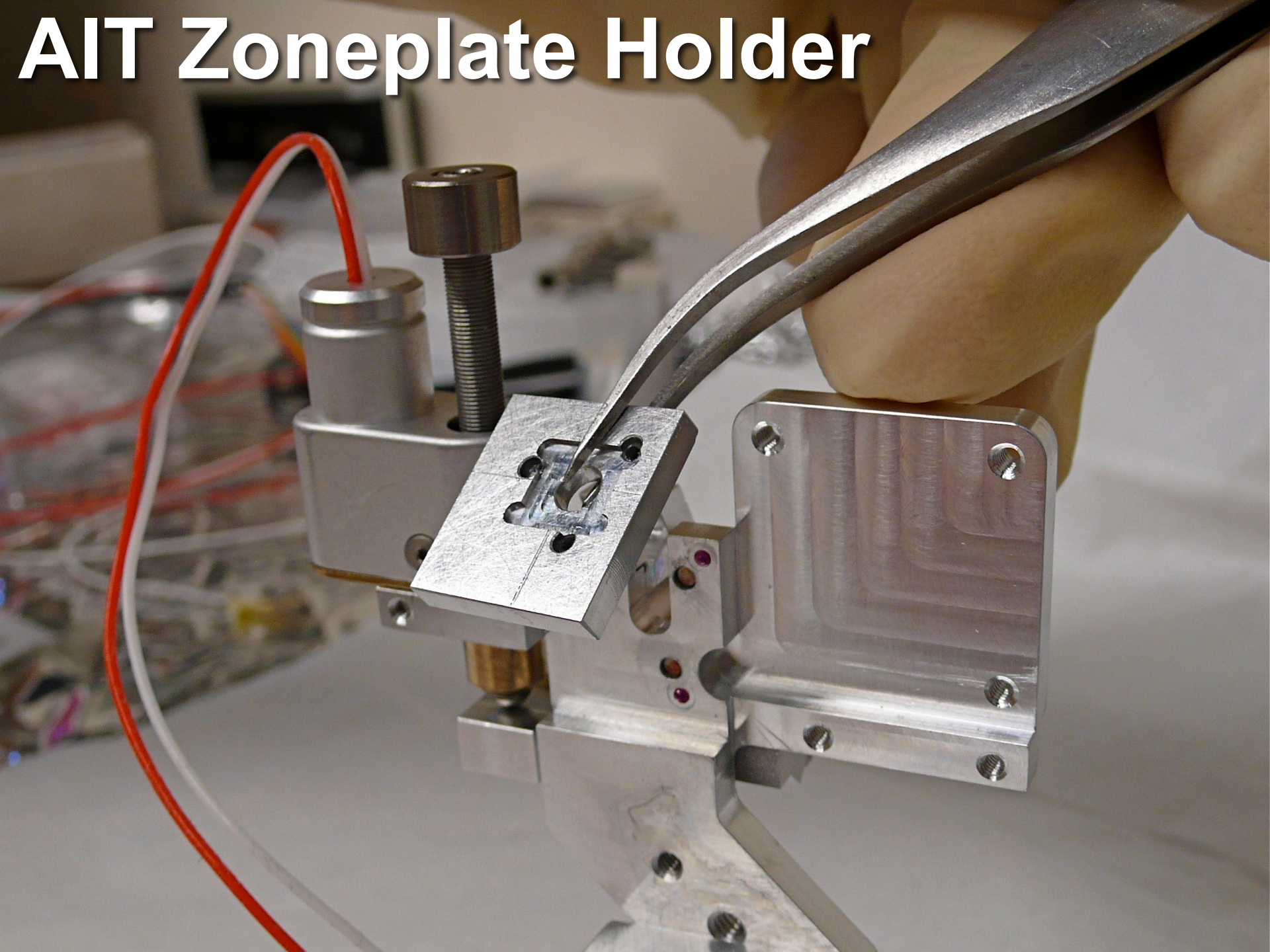
$$\text{Mag} = Z_{\text{ccd}} / f$$

$$\text{Bandwidth} \sim 1/N_{\text{zones}} \sim 1/f$$



$$\text{Intensity} \sim 1/f$$

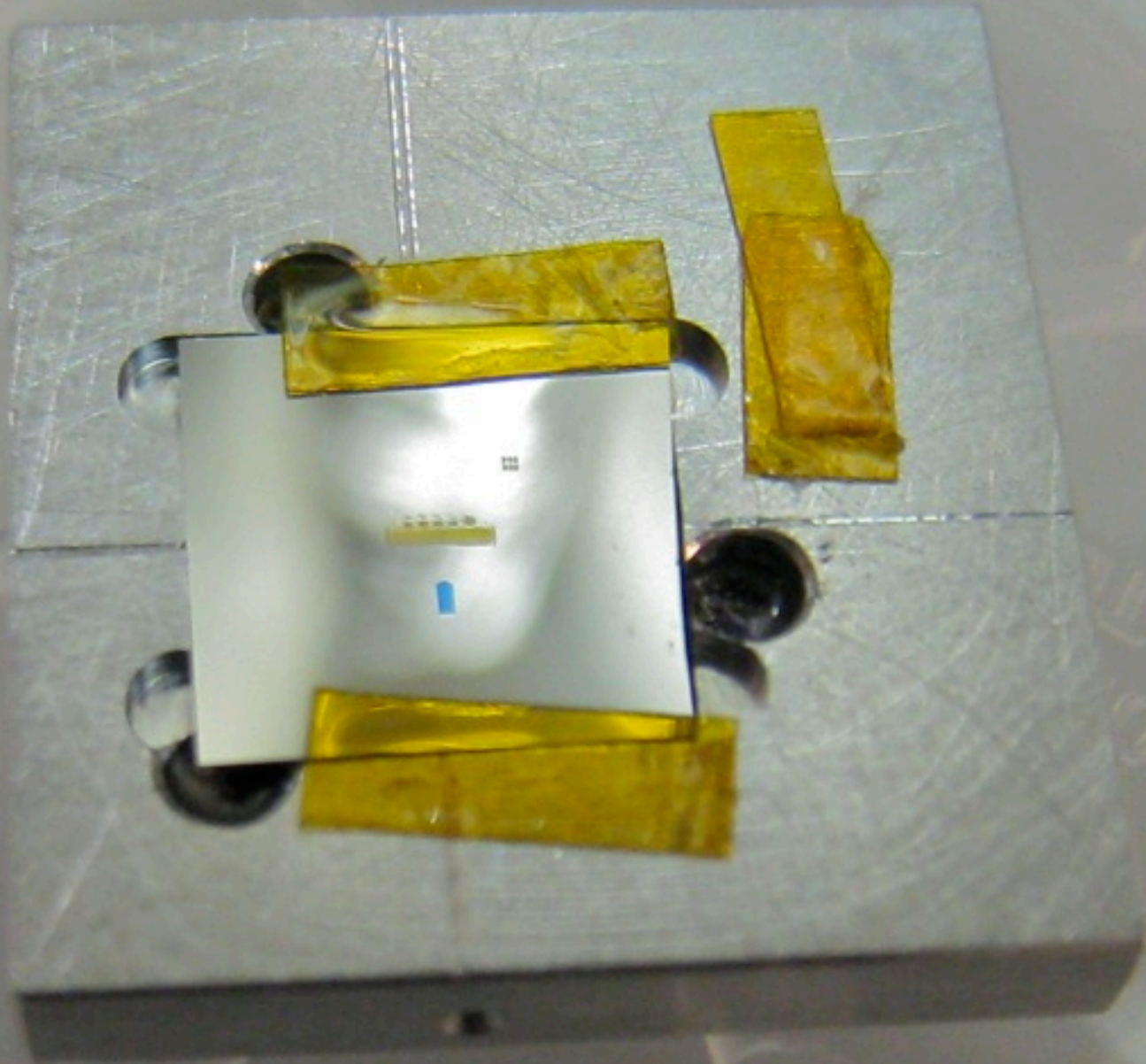
We want  $f =$   
 $750 \rightarrow 500 \rightarrow 250 \mu\text{m}$



# AIT Zoneplate Holder

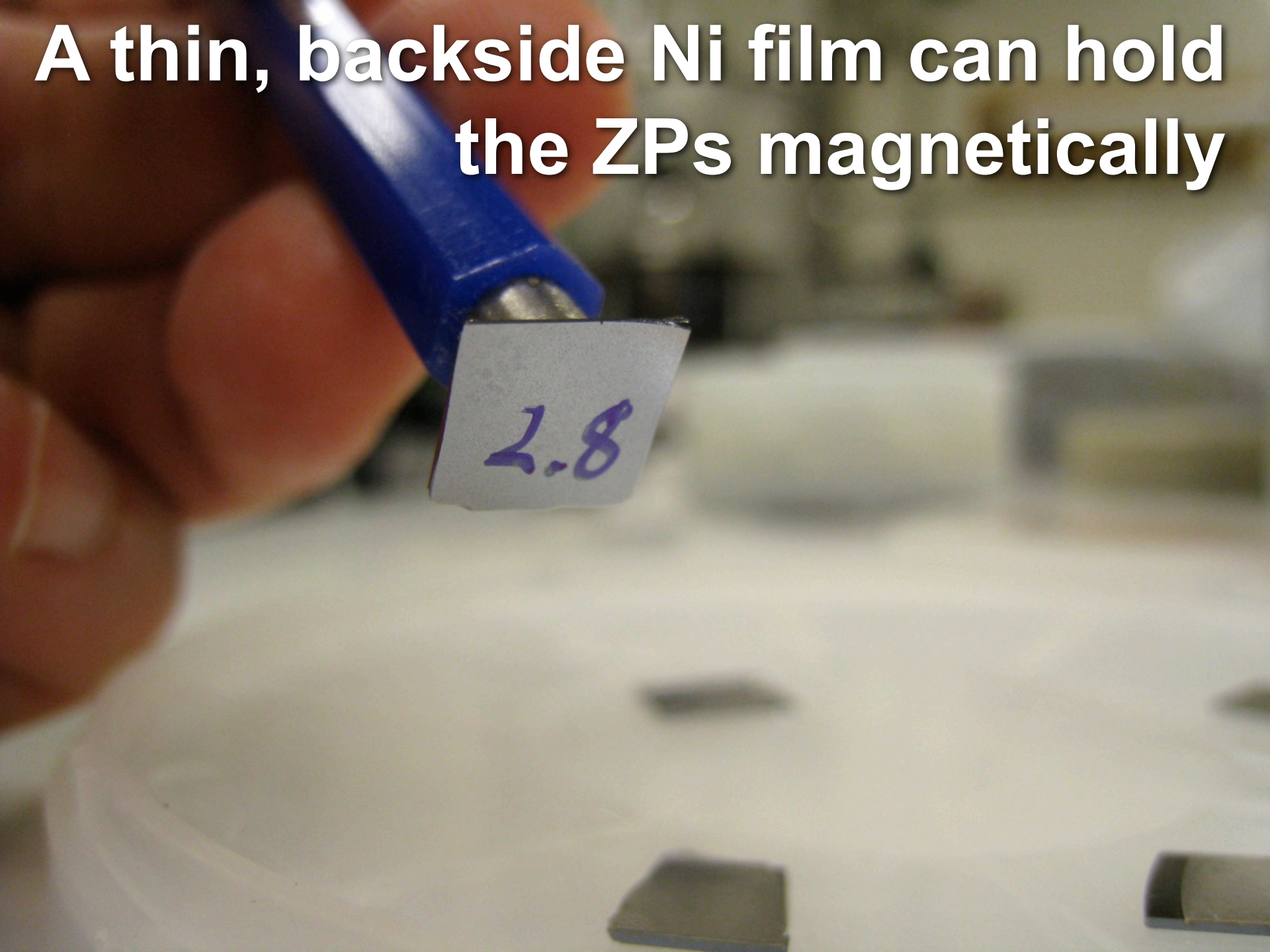


# AIT Zoneplate Array, in the holder





**A thin, backside Ni film can hold  
the ZPs magnetically**

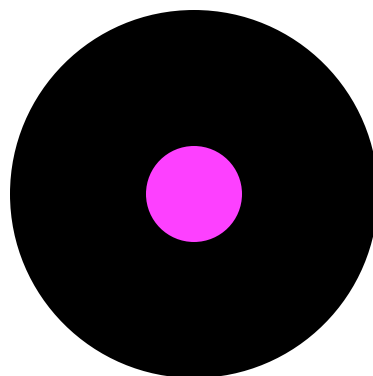




# COHERENCE

The background of the image is a dark green field filled with numerous bright green laser lines. These lines originate from a single, intense white point on the right side of the frame and radiate outwards in all directions, creating a starburst or sunburst effect. The lines vary in thickness and brightness, with some appearing as sharp, thin streaks and others as slightly thicker, more diffuse beams. The overall effect is one of dynamic energy and focus, centered around the point of origin on the right.

# Fourier-Synthesis Illuminator

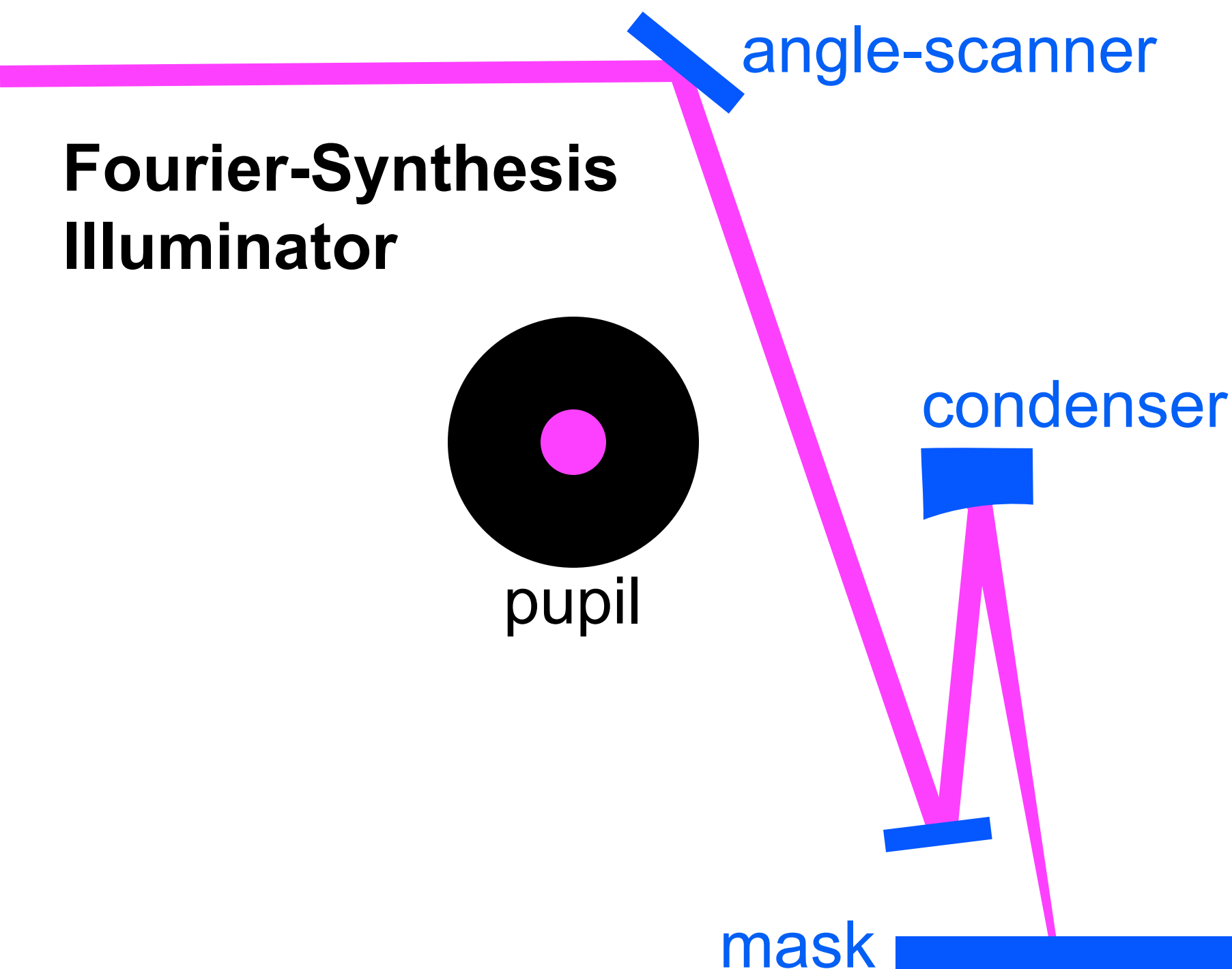


pupil

angle-scanner

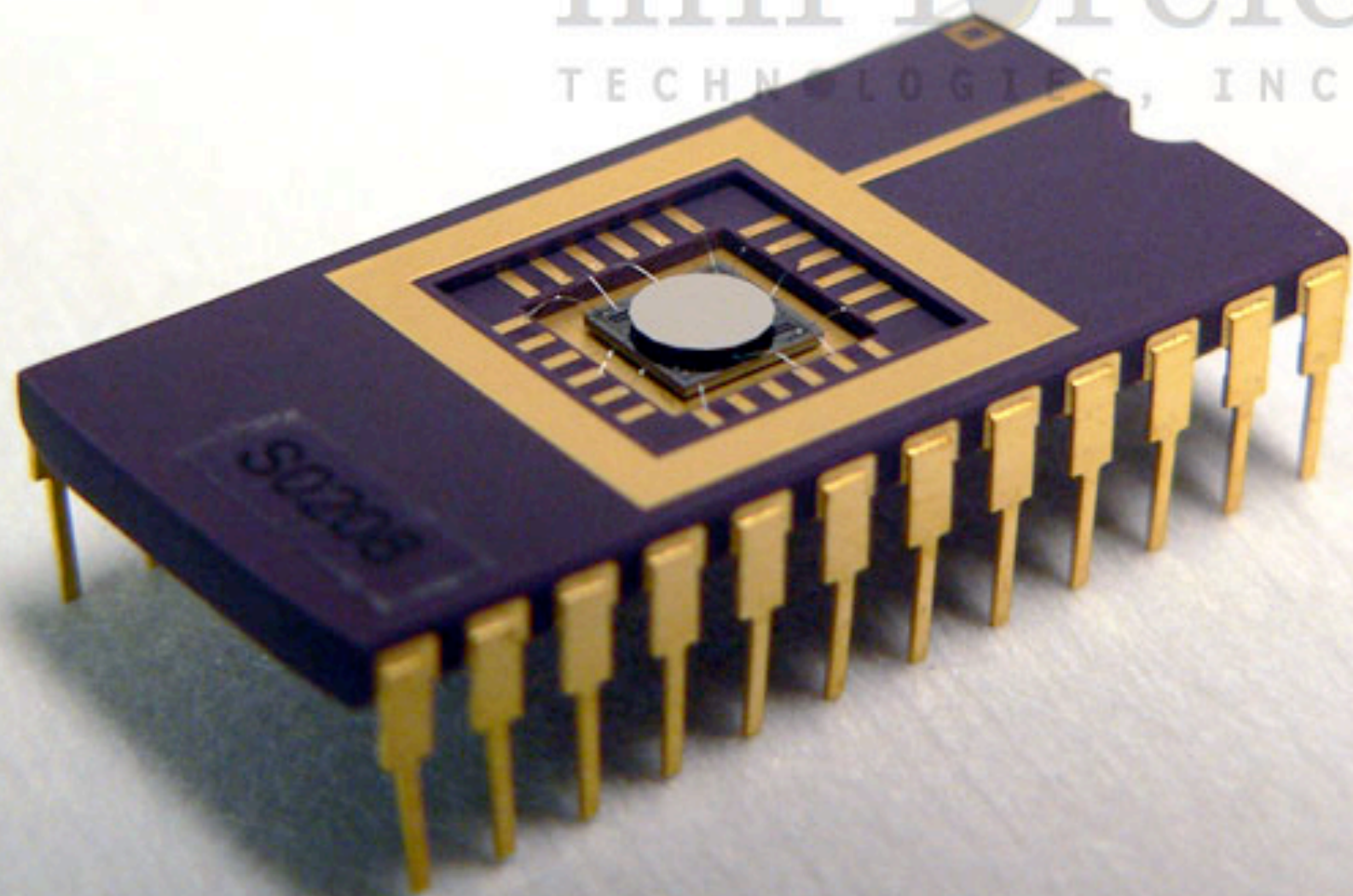
condenser

mask



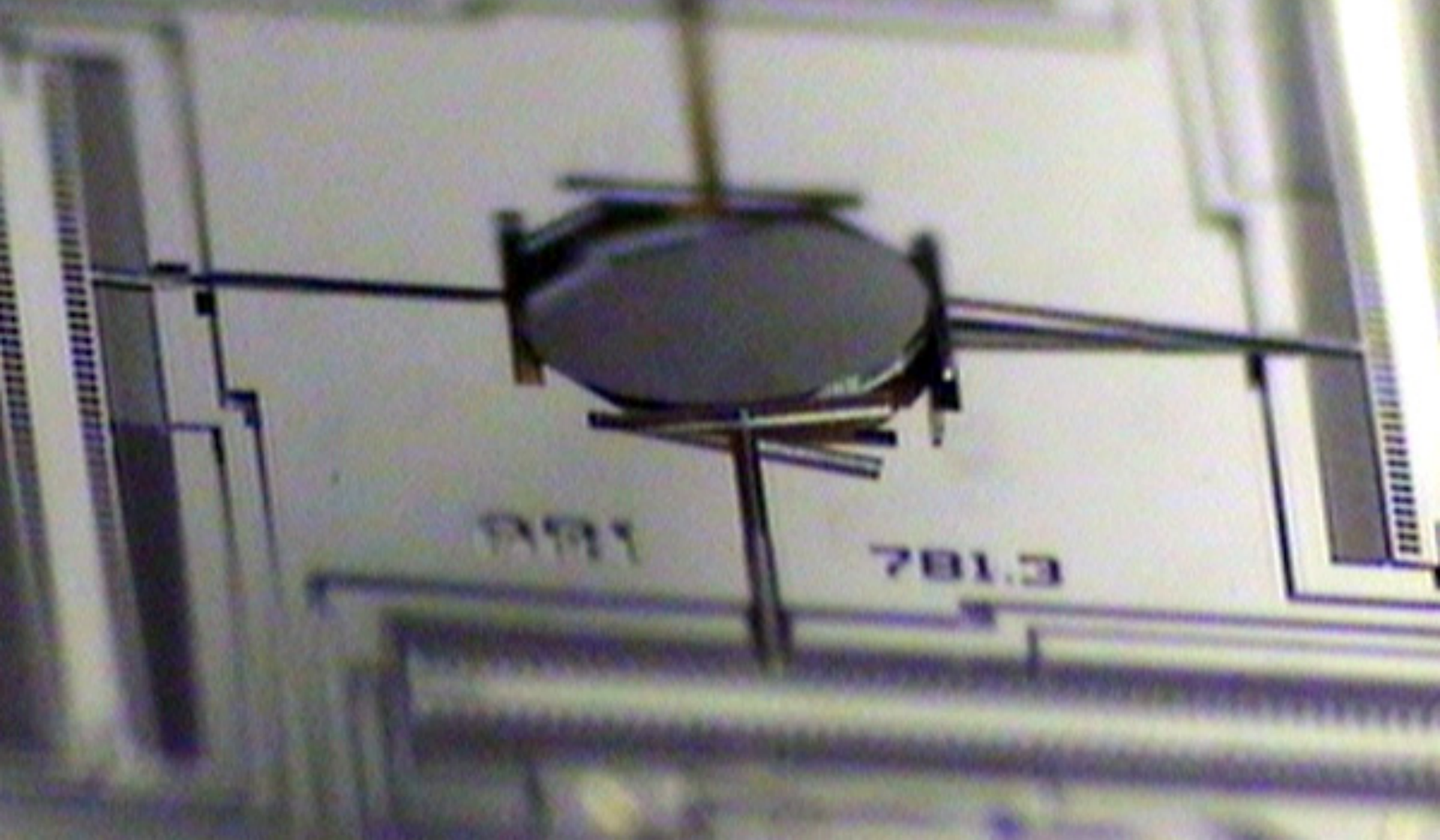


mirr<sup>o</sup>rcle  
TECHNOLOGIES, INC.



# mirracle

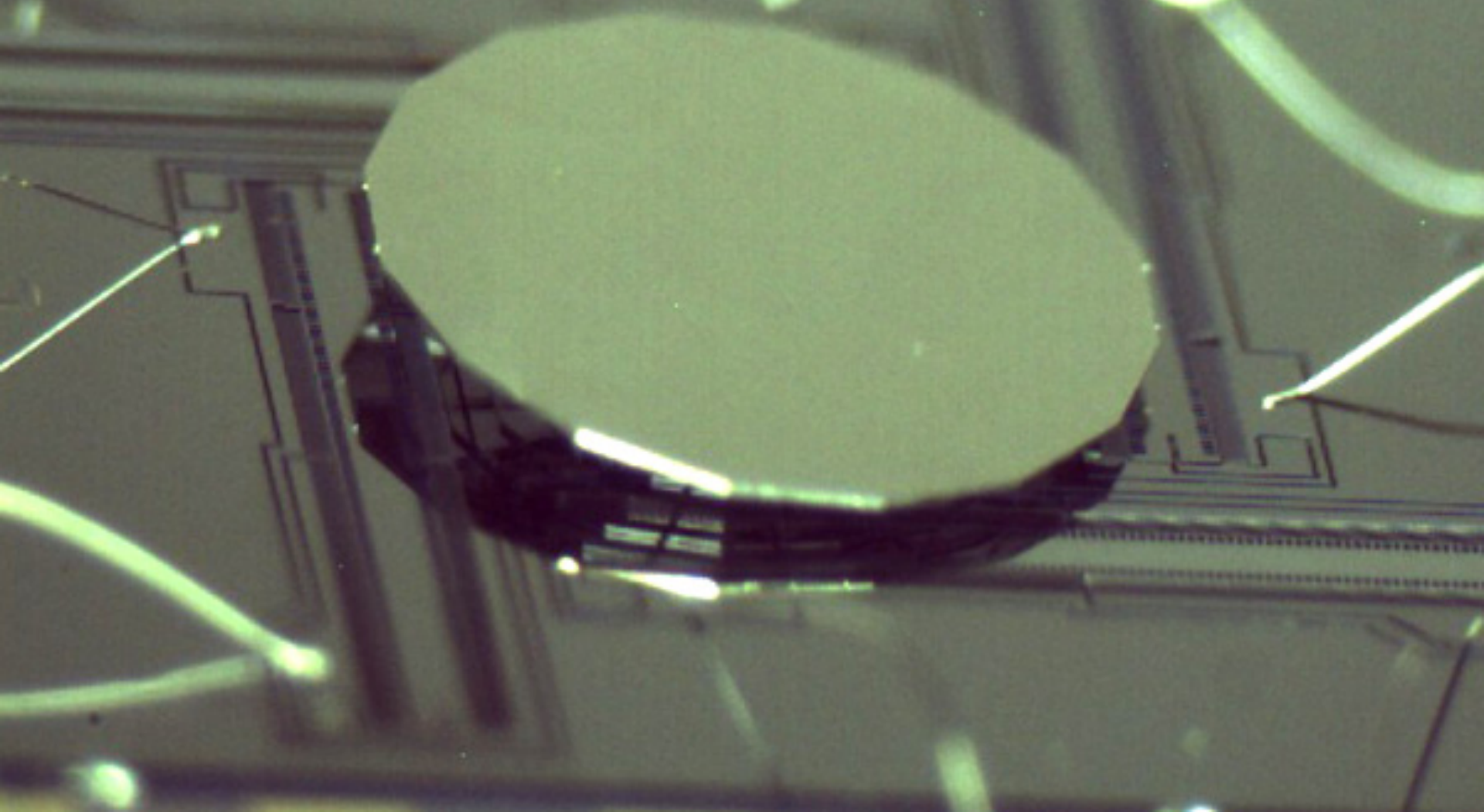
TECHNOLOGIES, INC.





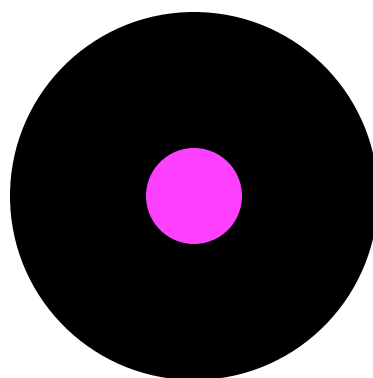
# mirrored

TECHNOLOGIES, INC.





# Fourier-Synthesis Illuminator

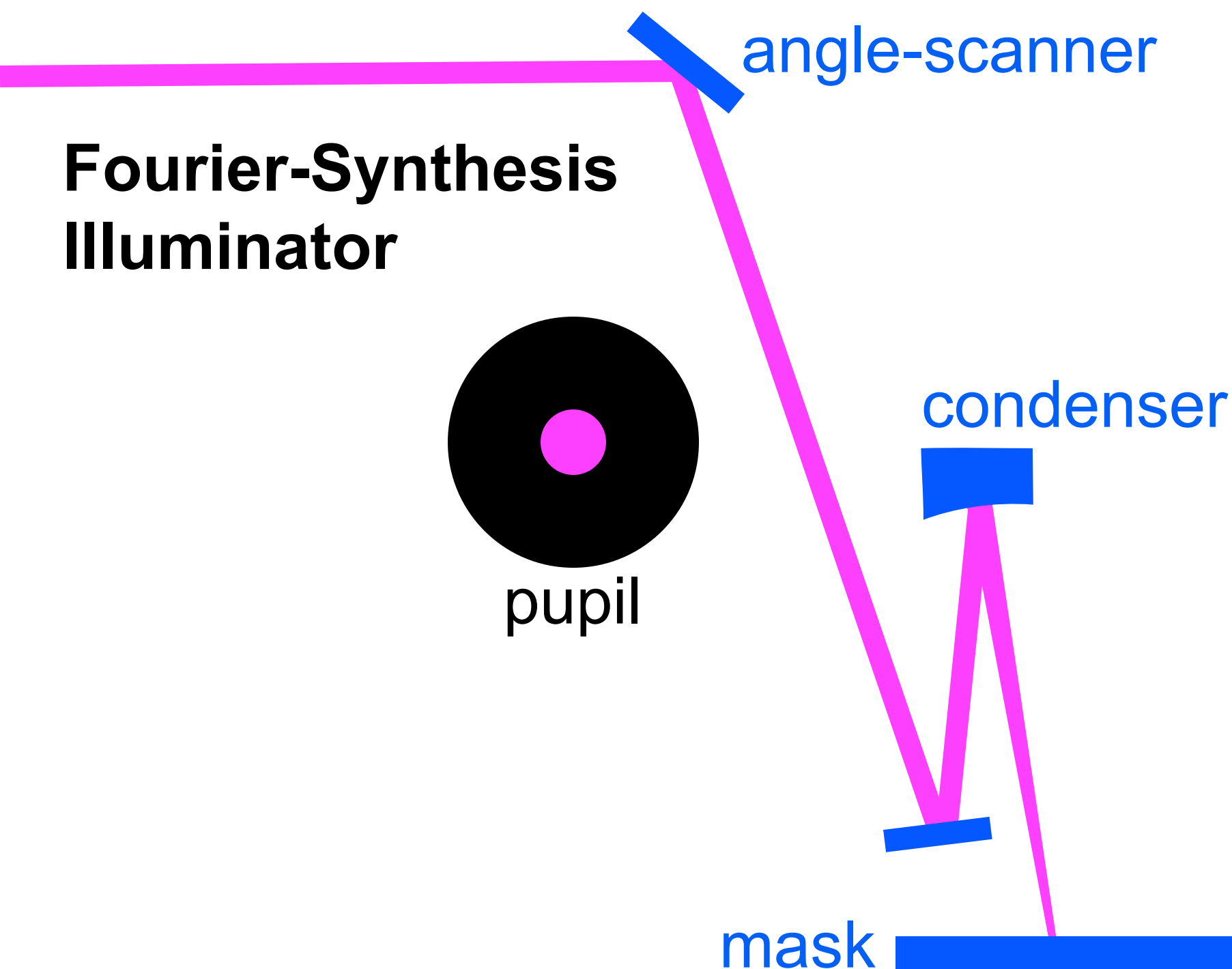


pupil

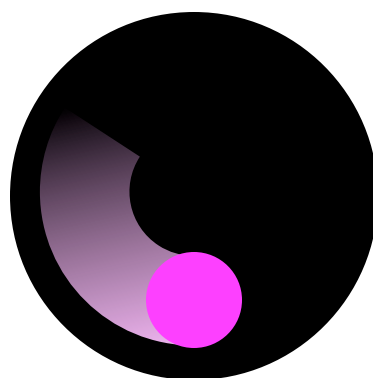
angle-scanner

condenser

mask



# Fourier-Synthesis Illuminator

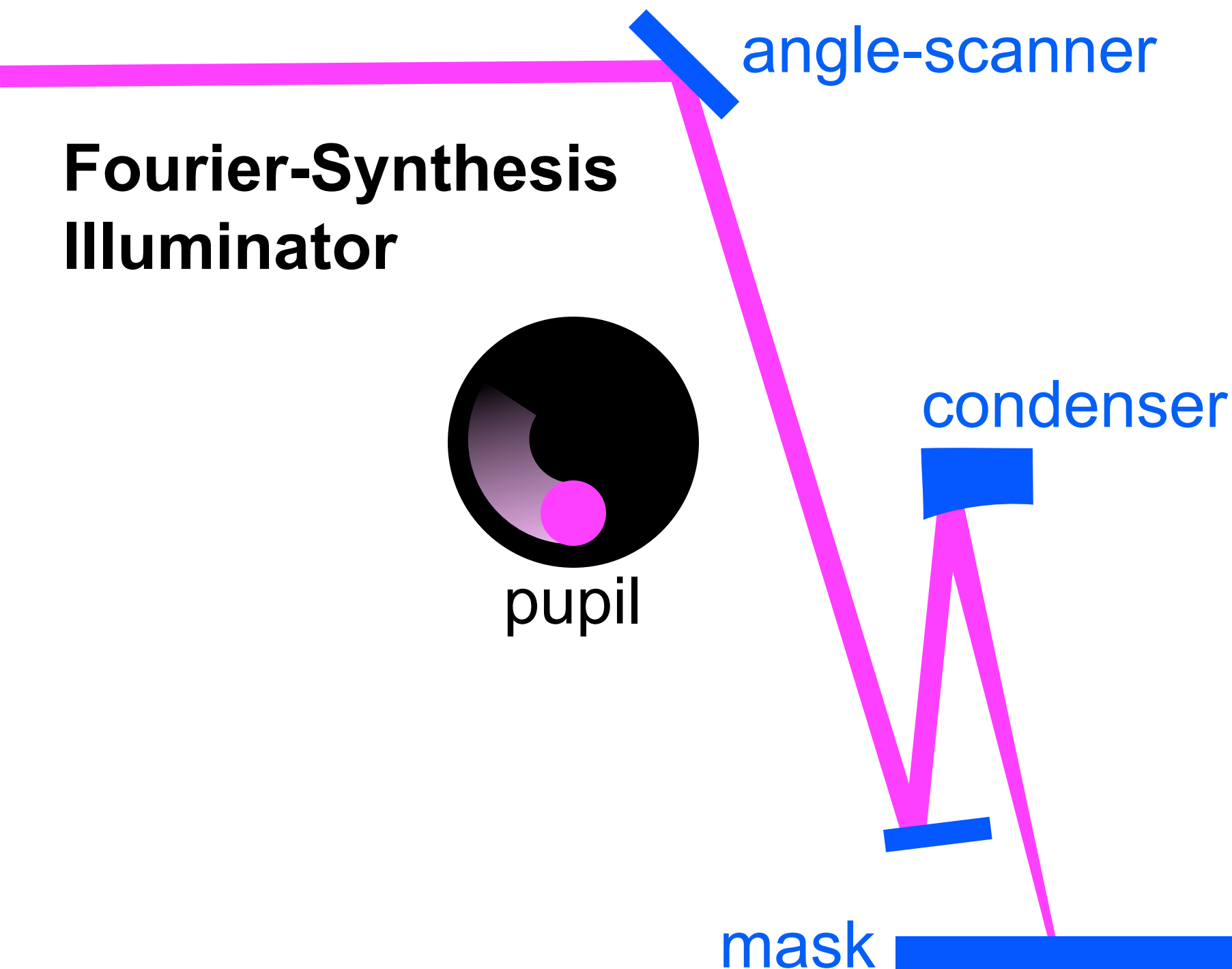


pupil

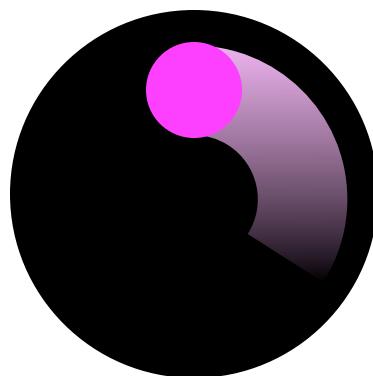
angle-scanner

condenser

mask



# Fourier-Synthesis Illuminator

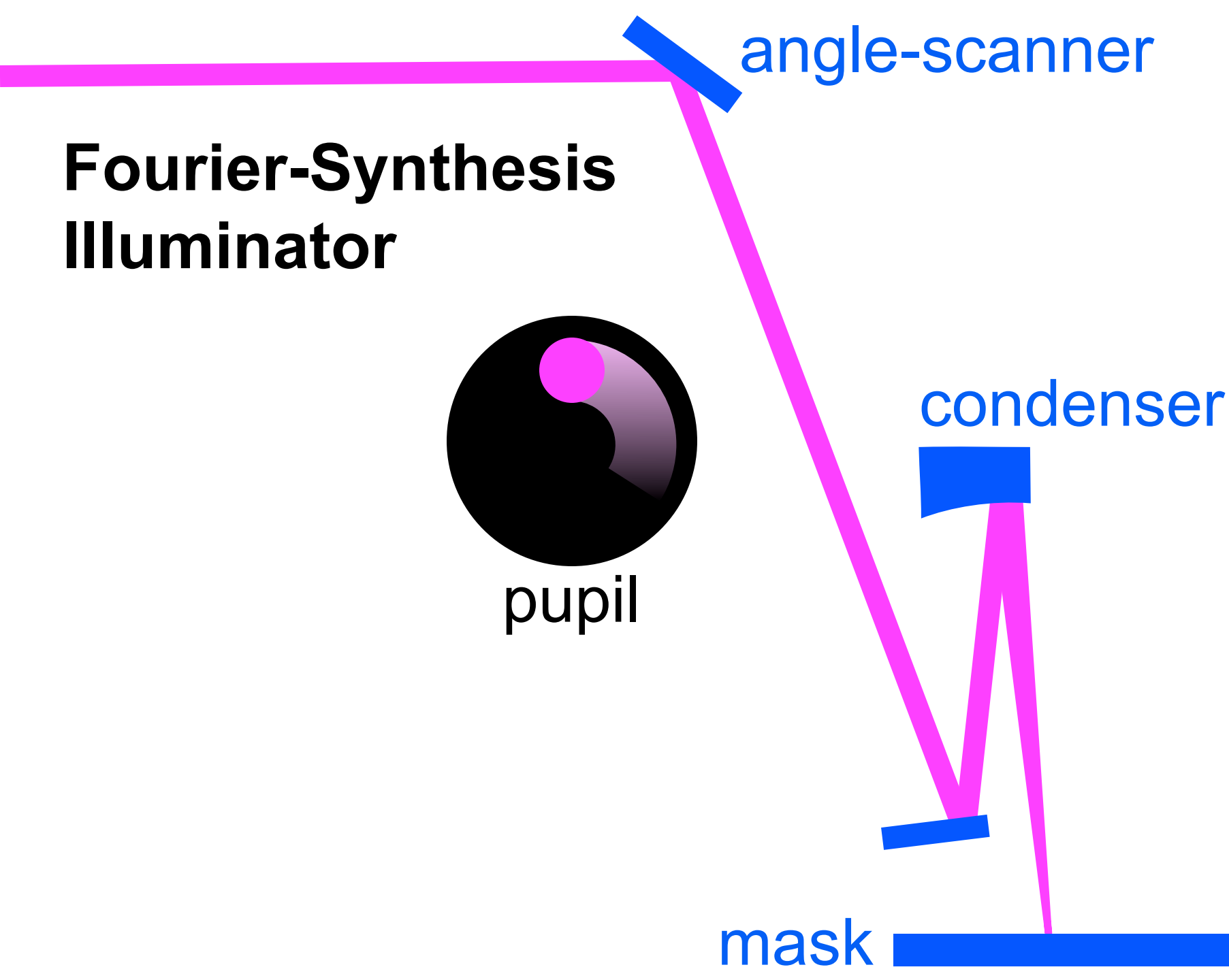


pupil

angle-scanner

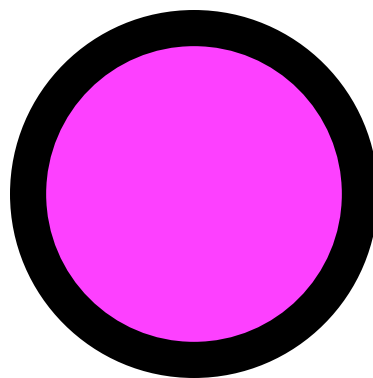
condenser

mask





# Fourier-Synthesis Illuminator

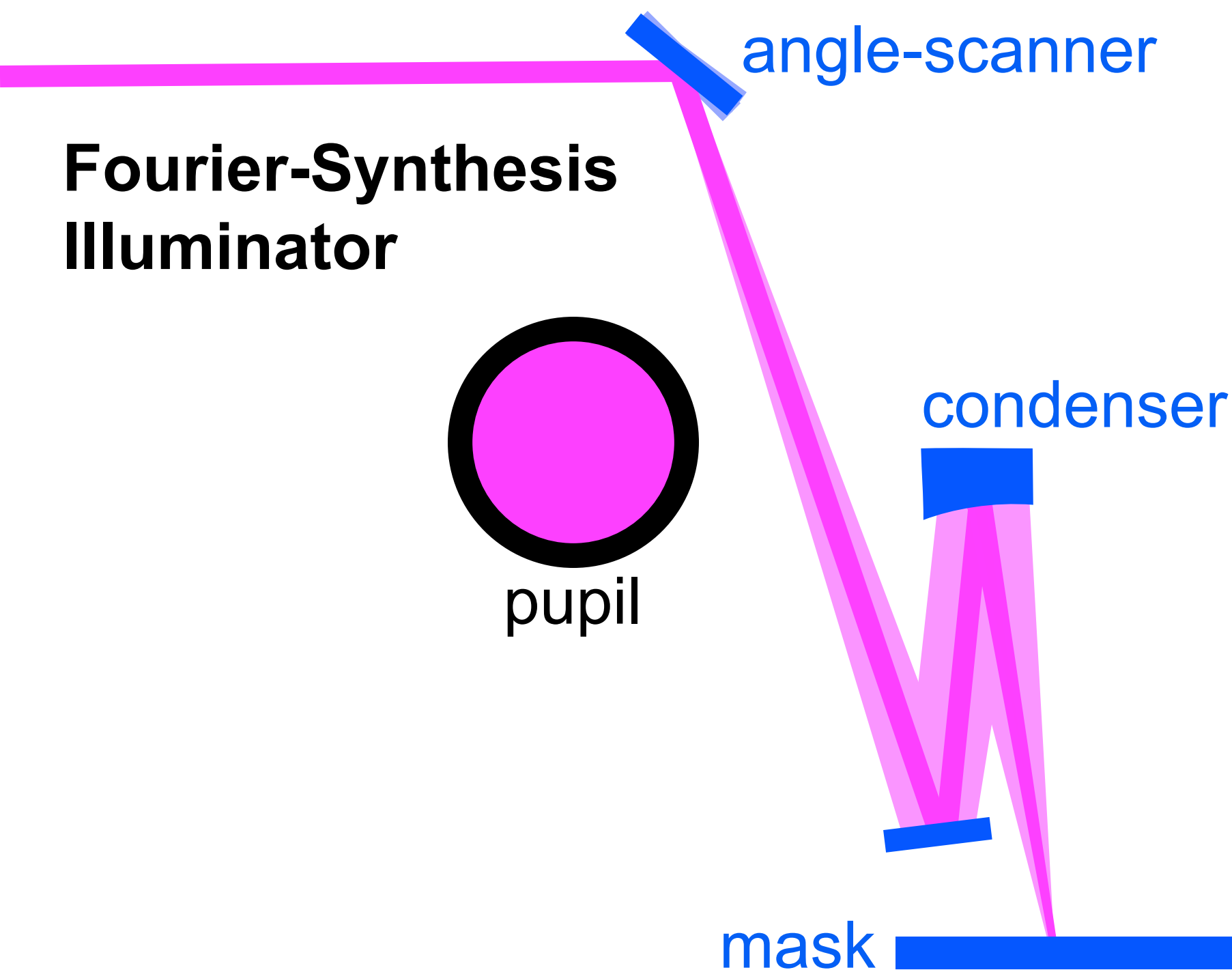


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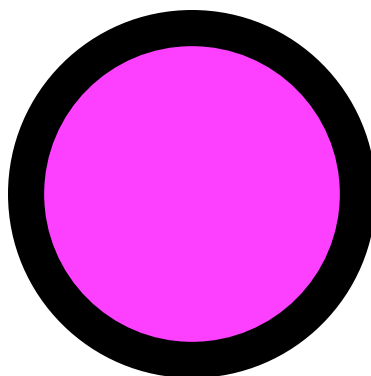
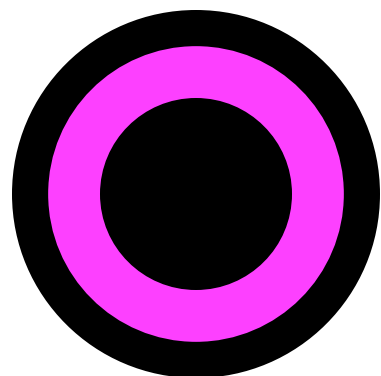
angle-scanner

condenser

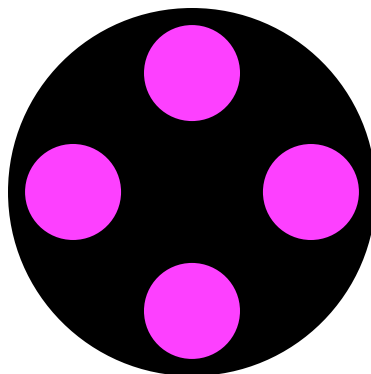
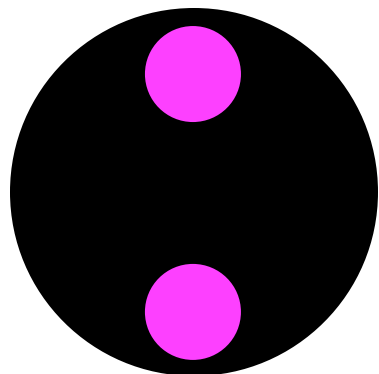
mask



# Fourier-Synthesis Illuminator



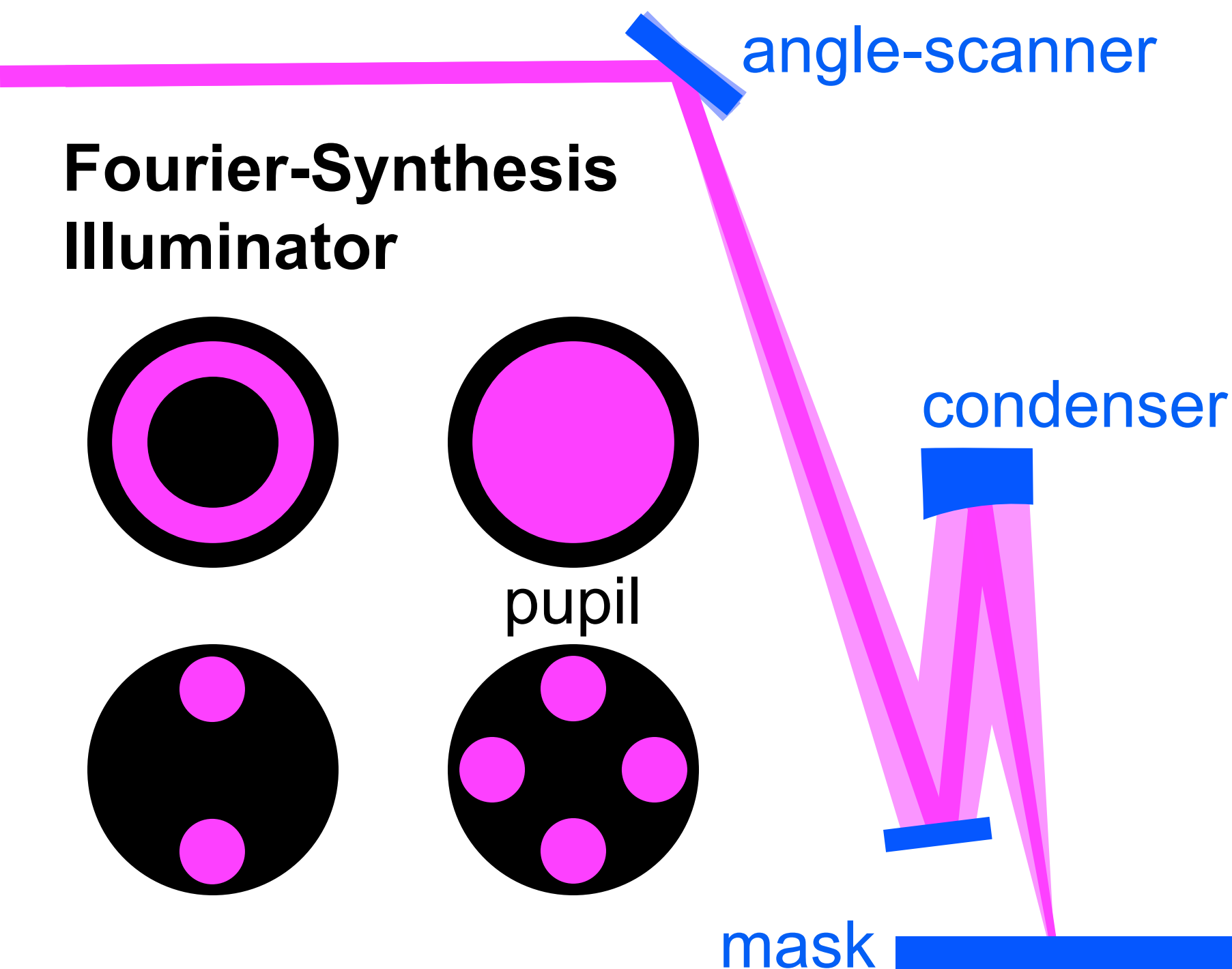
pupil

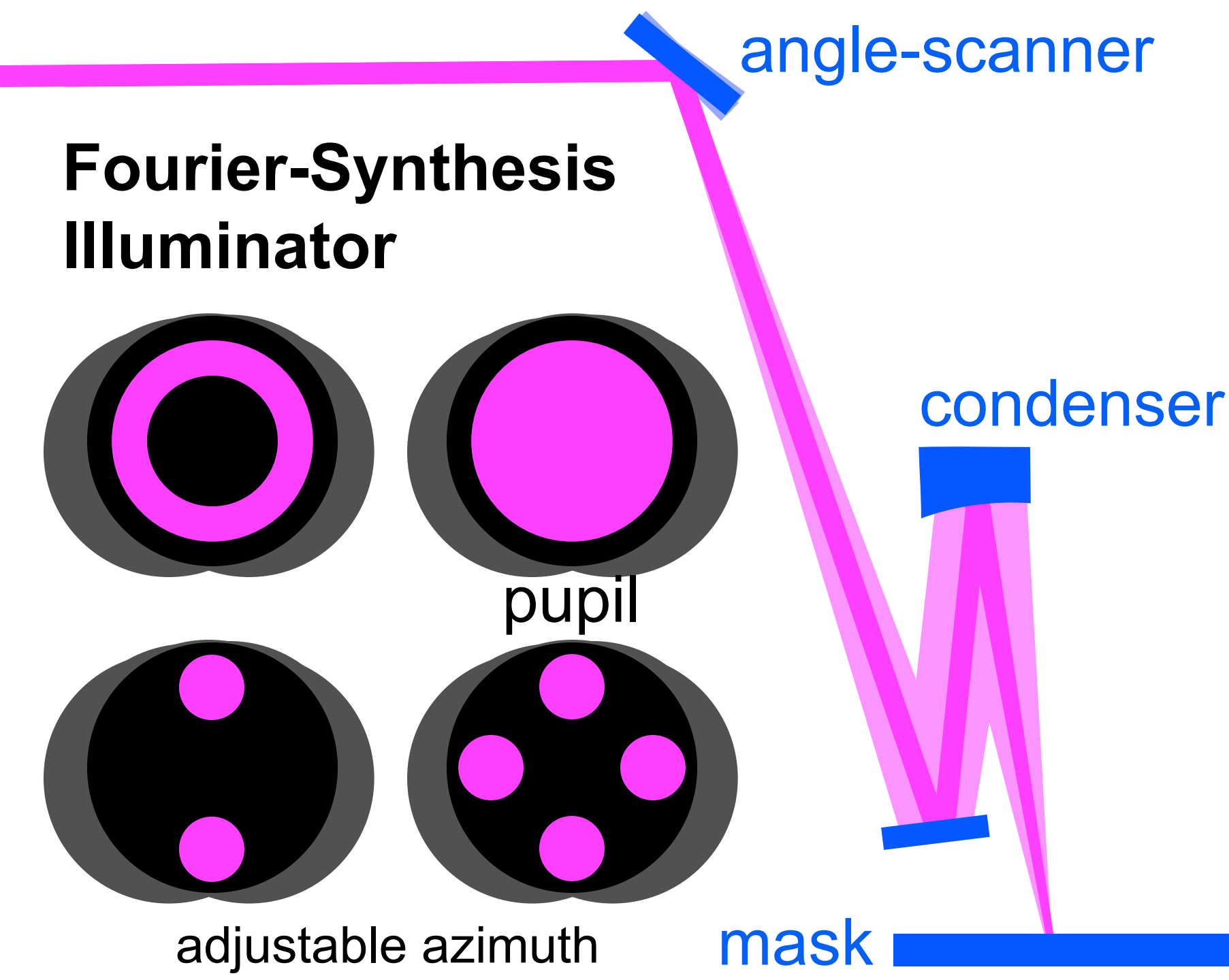


angle-scanner

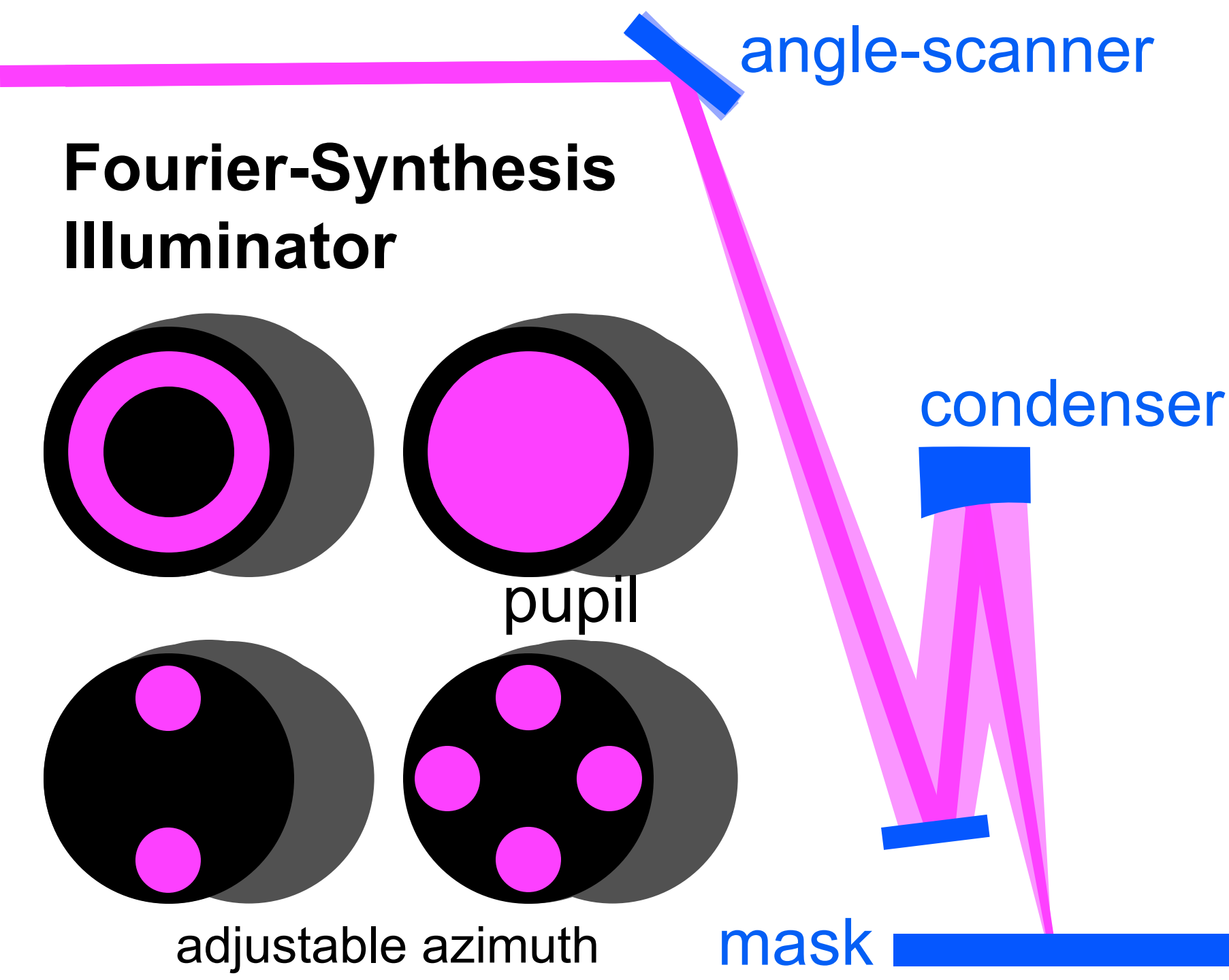
condenser

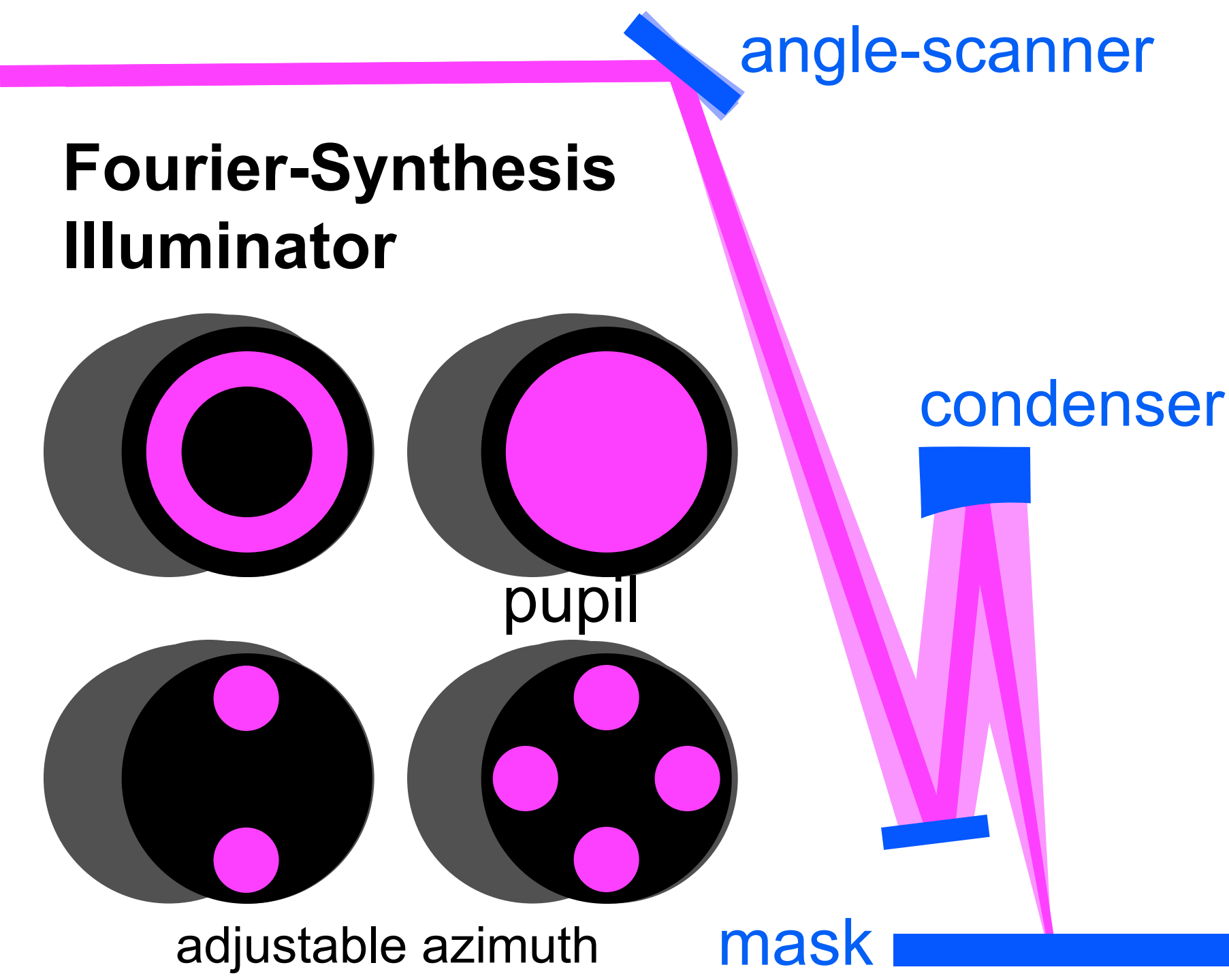
mask

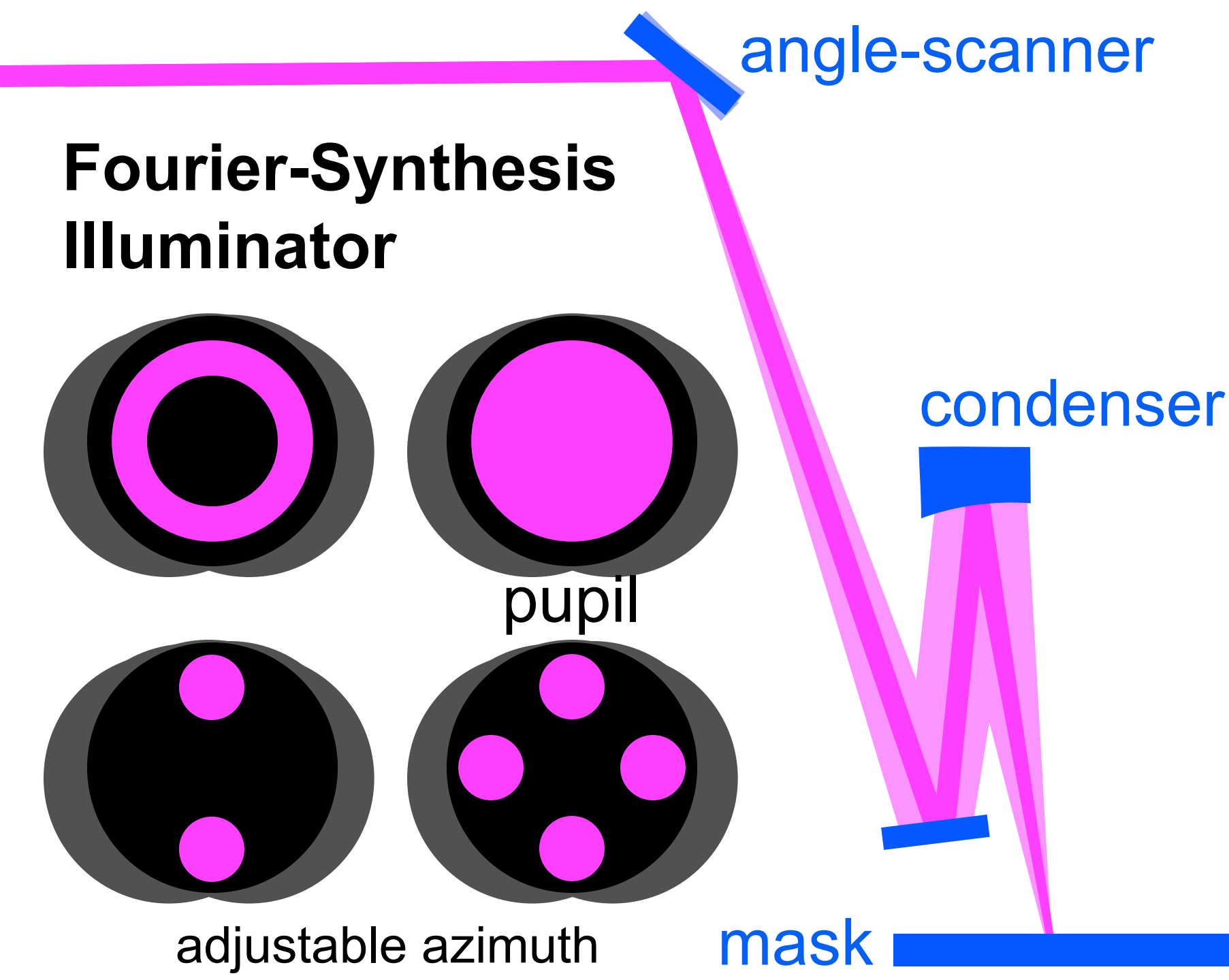












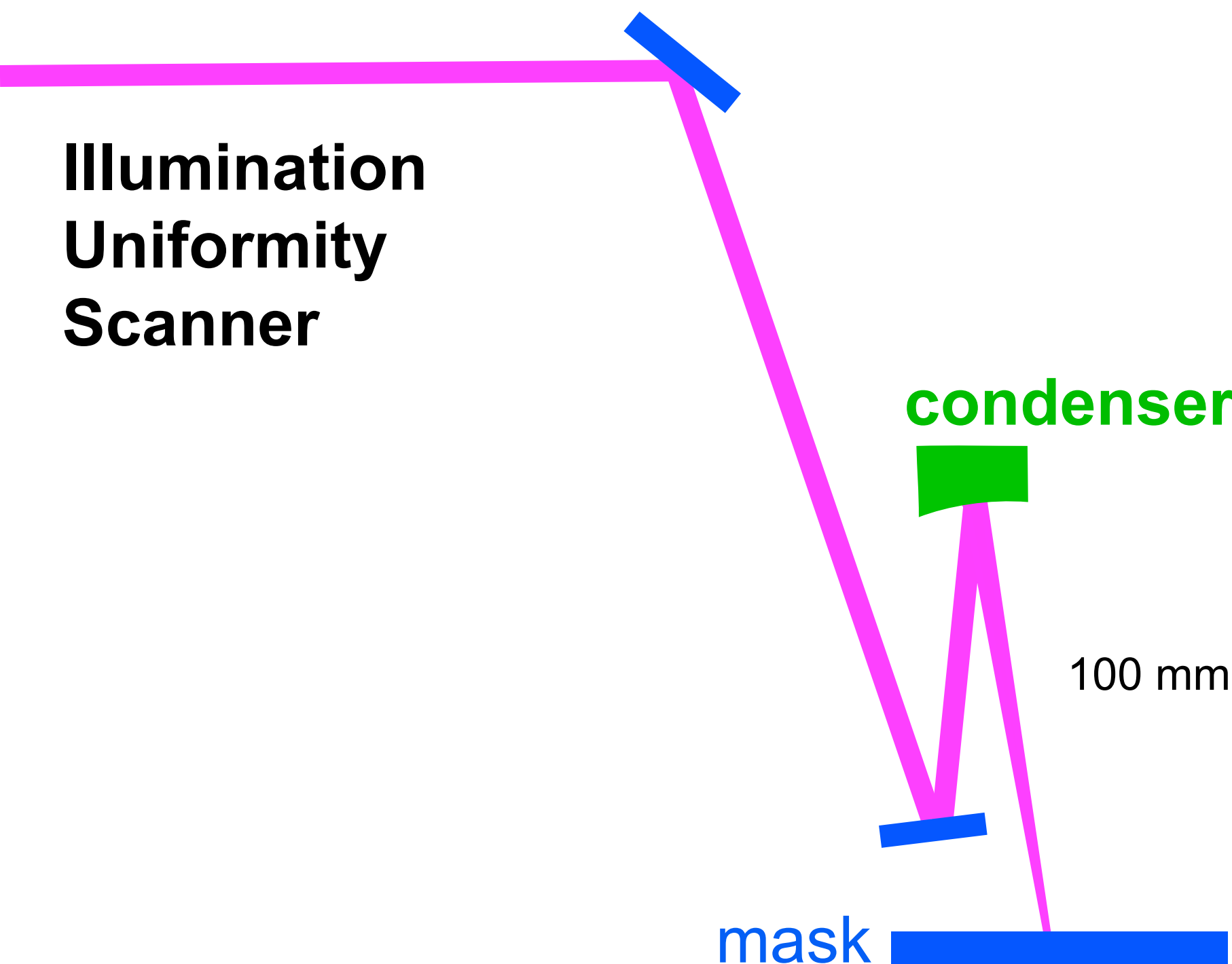


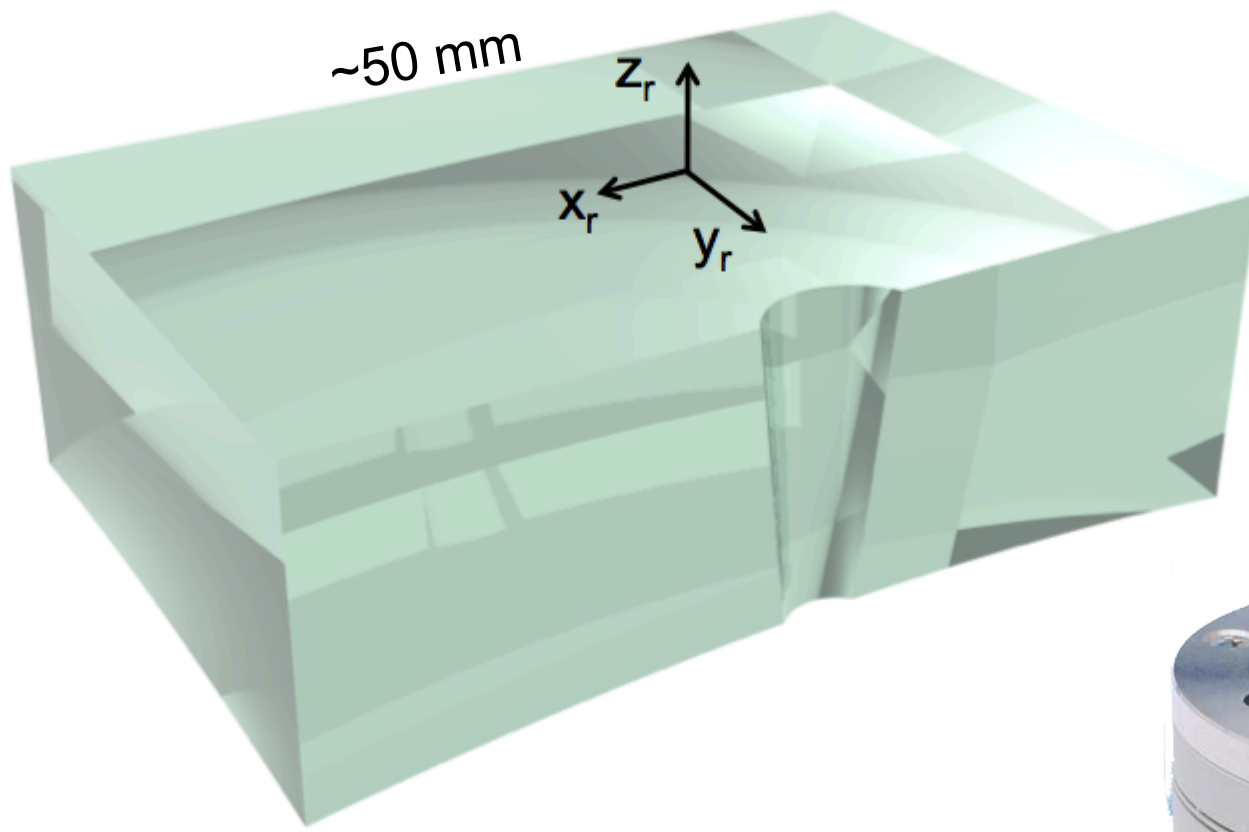
**Illumination  
Uniformity  
Scanner**

**condenser**

100 mm

**mask**





# SHARP Condenser



Unmodified  
S-340.AL Tip/Tilt Platform

# Illumination Uniformity Scanner

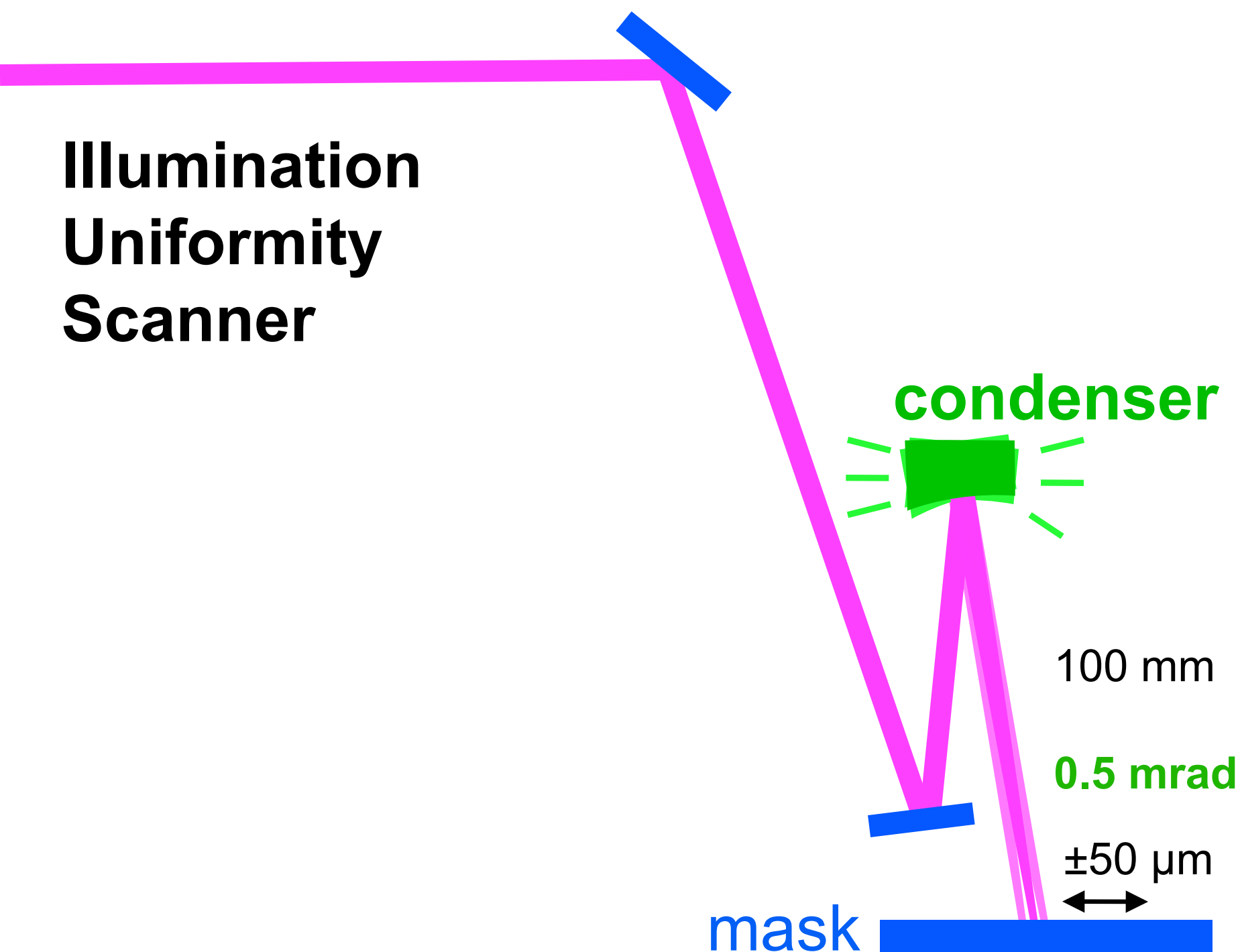
condenser

100 mm

0.5 mrad

$\pm 50 \mu\text{m}$

mask





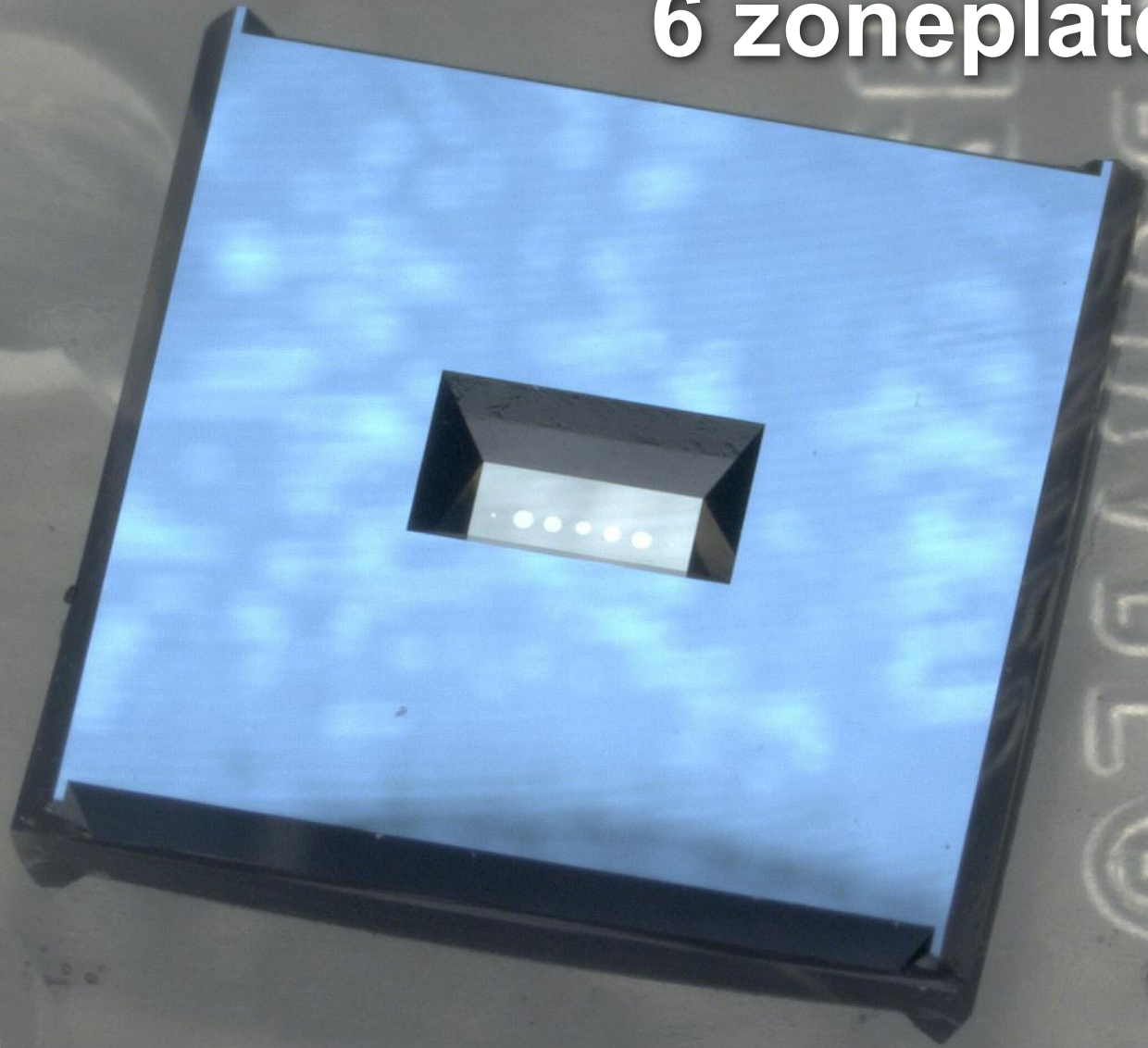
# FLEXIBLE





# AIT

## 6 zoneplates

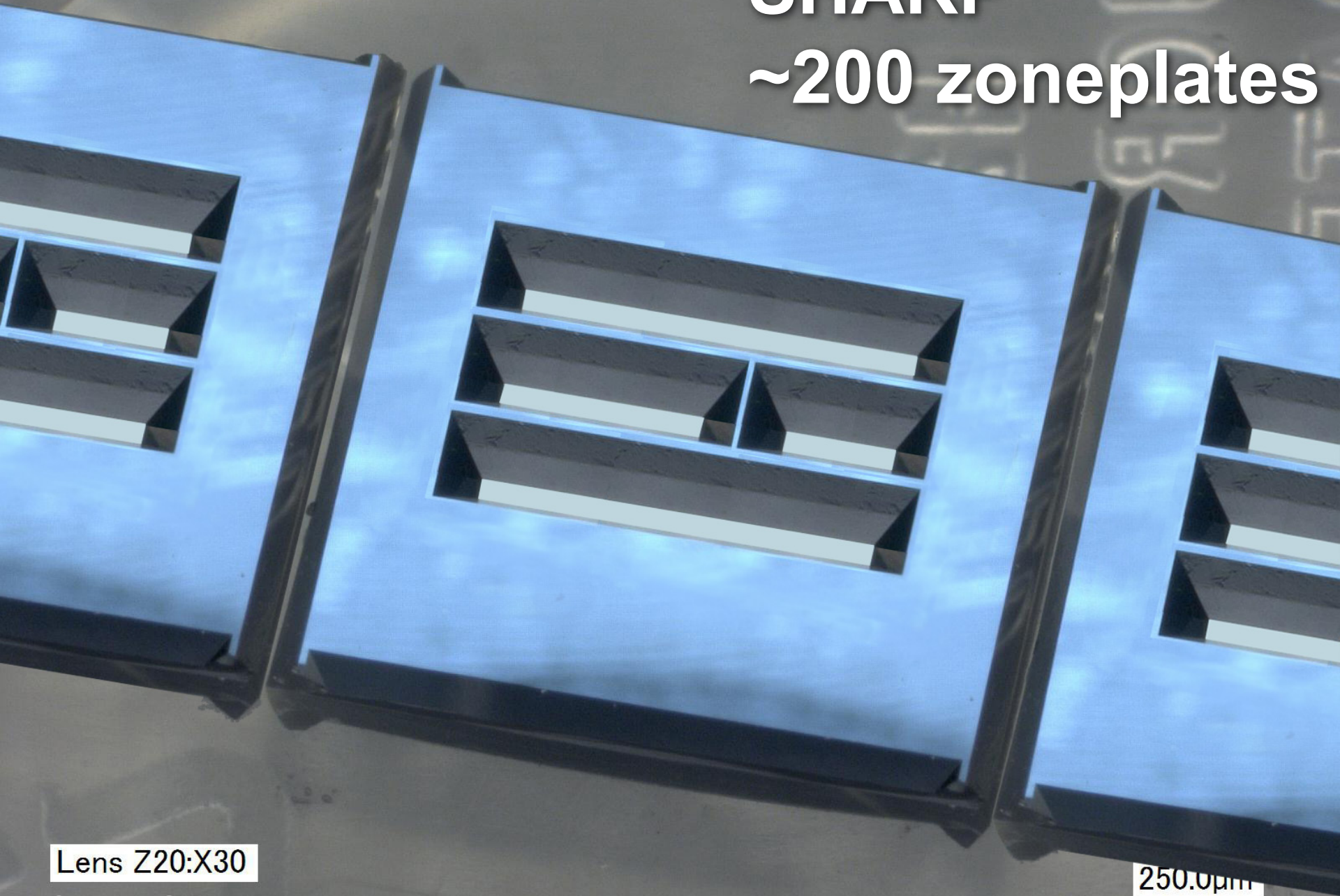


Lens Z20:X30

250.0μm

# SHARP

~200 zoneplates



Lens Z20:X30

250.0µm



# Various NA and Central Ray Angles

6°

8°

10°

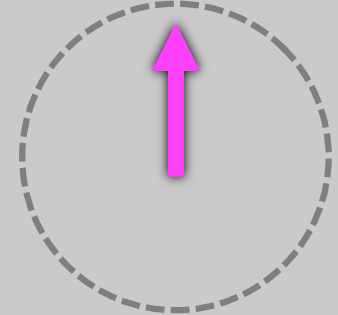
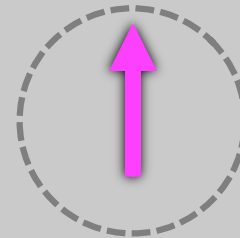
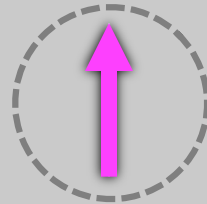
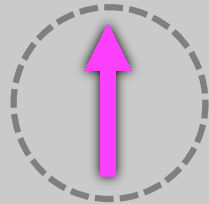
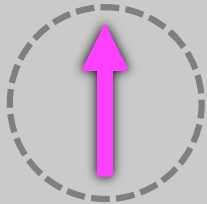
4xNA: 0.25

0.30

0.35

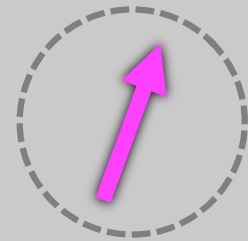
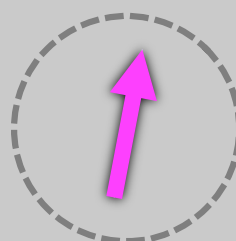
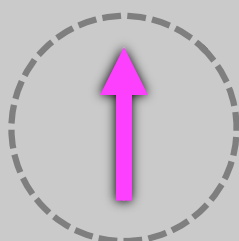
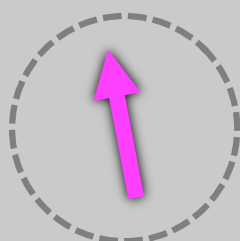
0.45

0.625



# Azimuthal angles, also important

$\Phi$ :  $-25^\circ$        $-12.5^\circ$        $0^\circ$        $12.5^\circ$        $25^\circ$





# STABLE



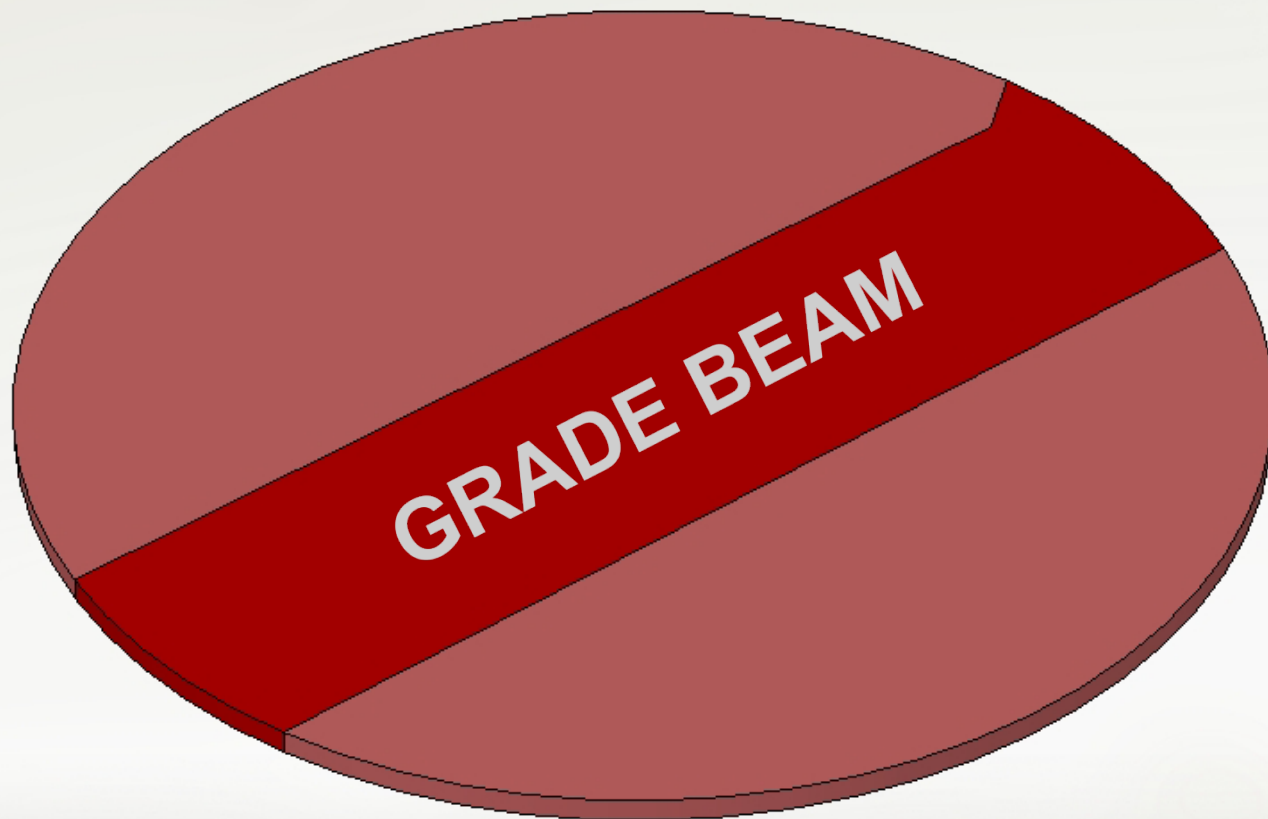


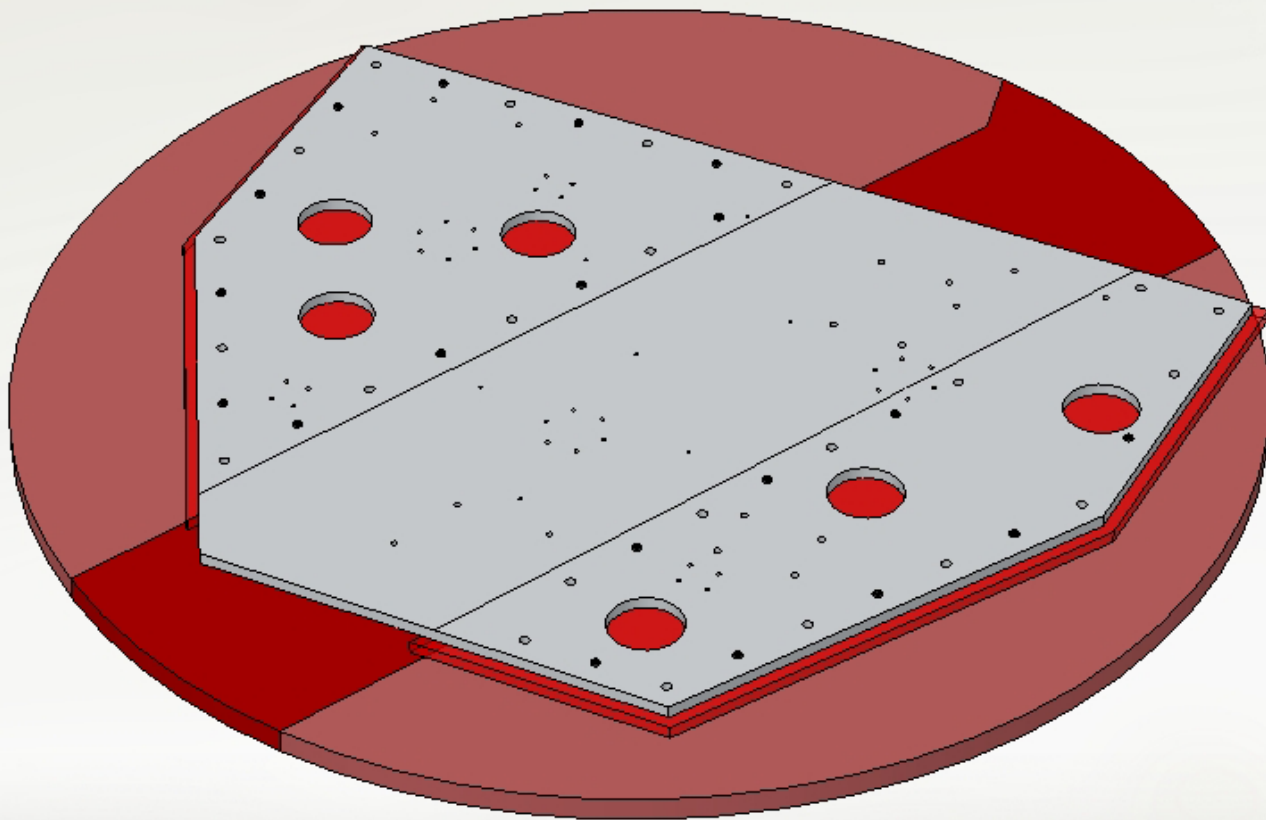


**Arnaud Allezy, Seno Rekawa**  
CXRO, LBNL



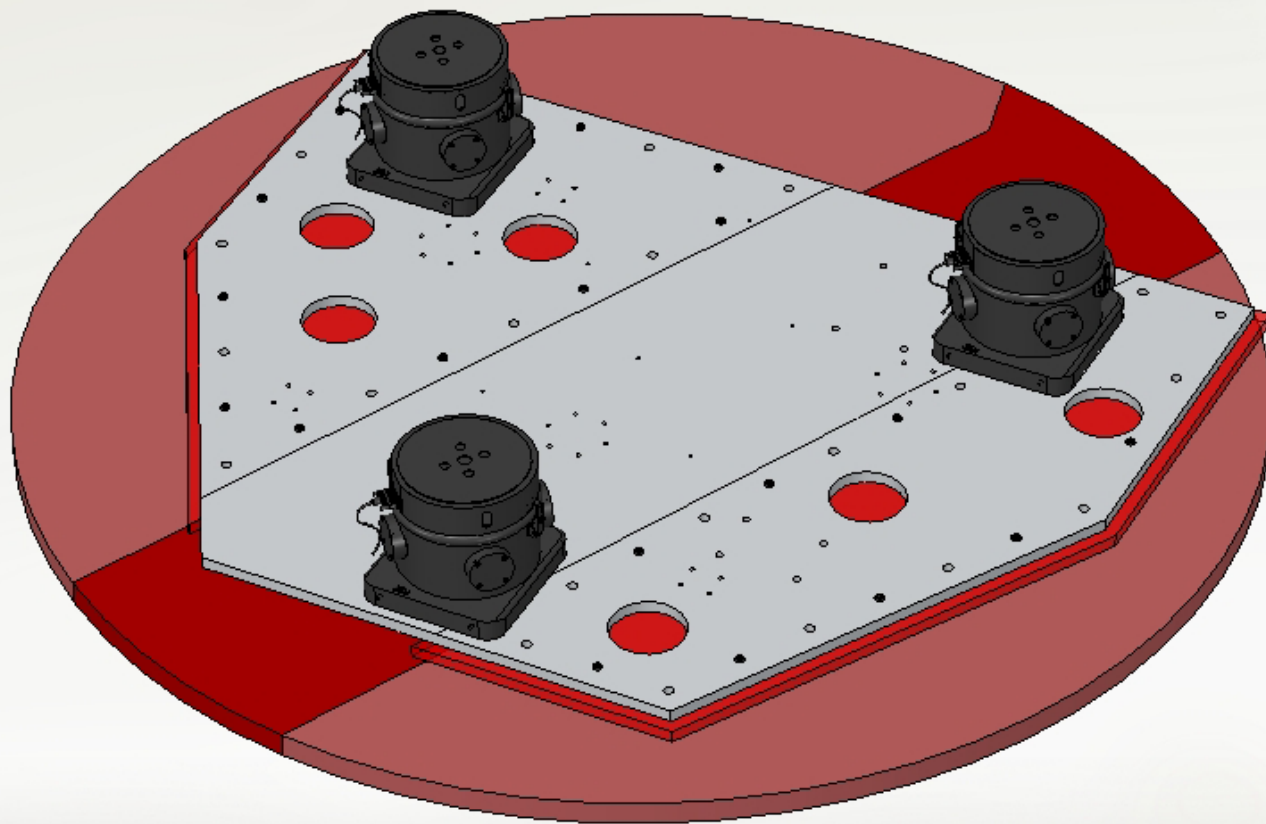
**Eric Acome, Eric Van Every**  
ADC, USA



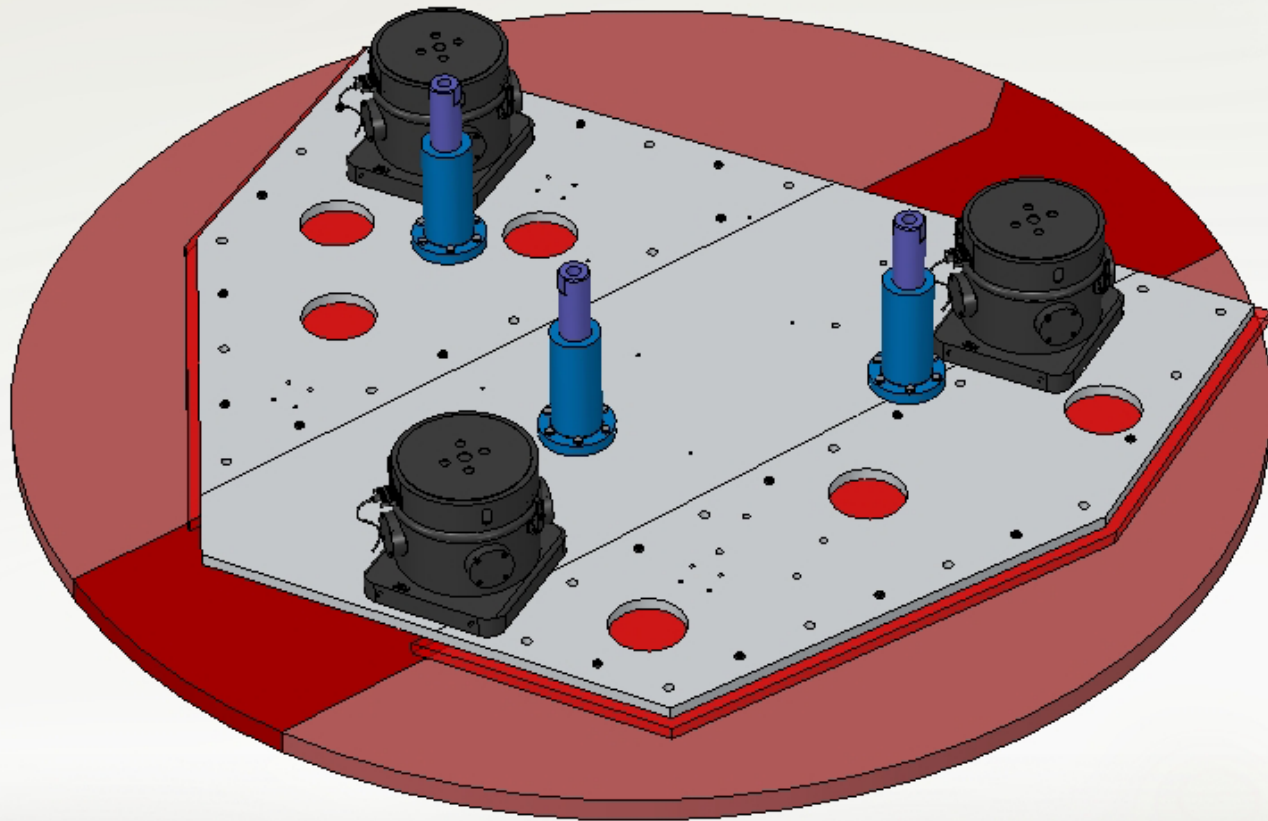


Grout: CHOKFAST® Red SG

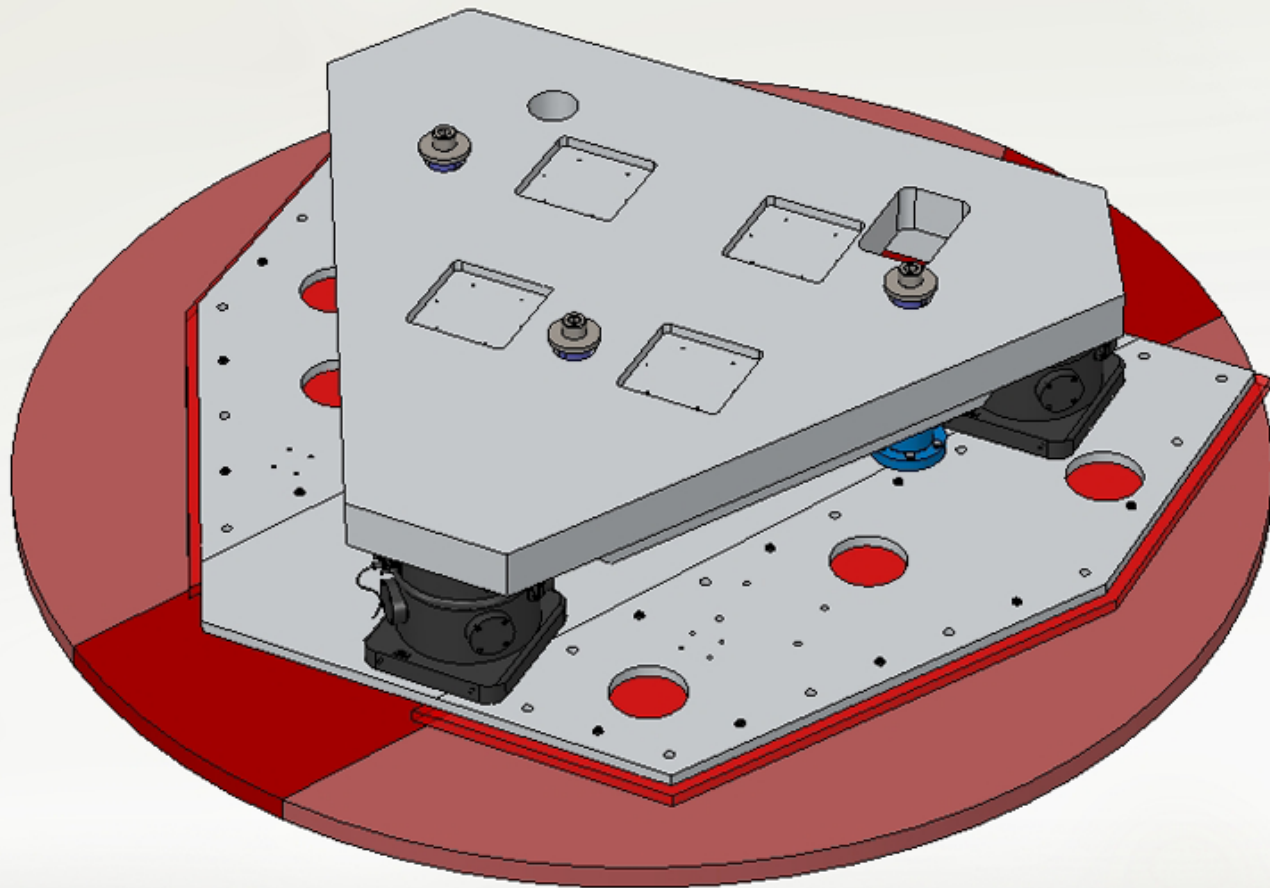




TMC Stacis 2100

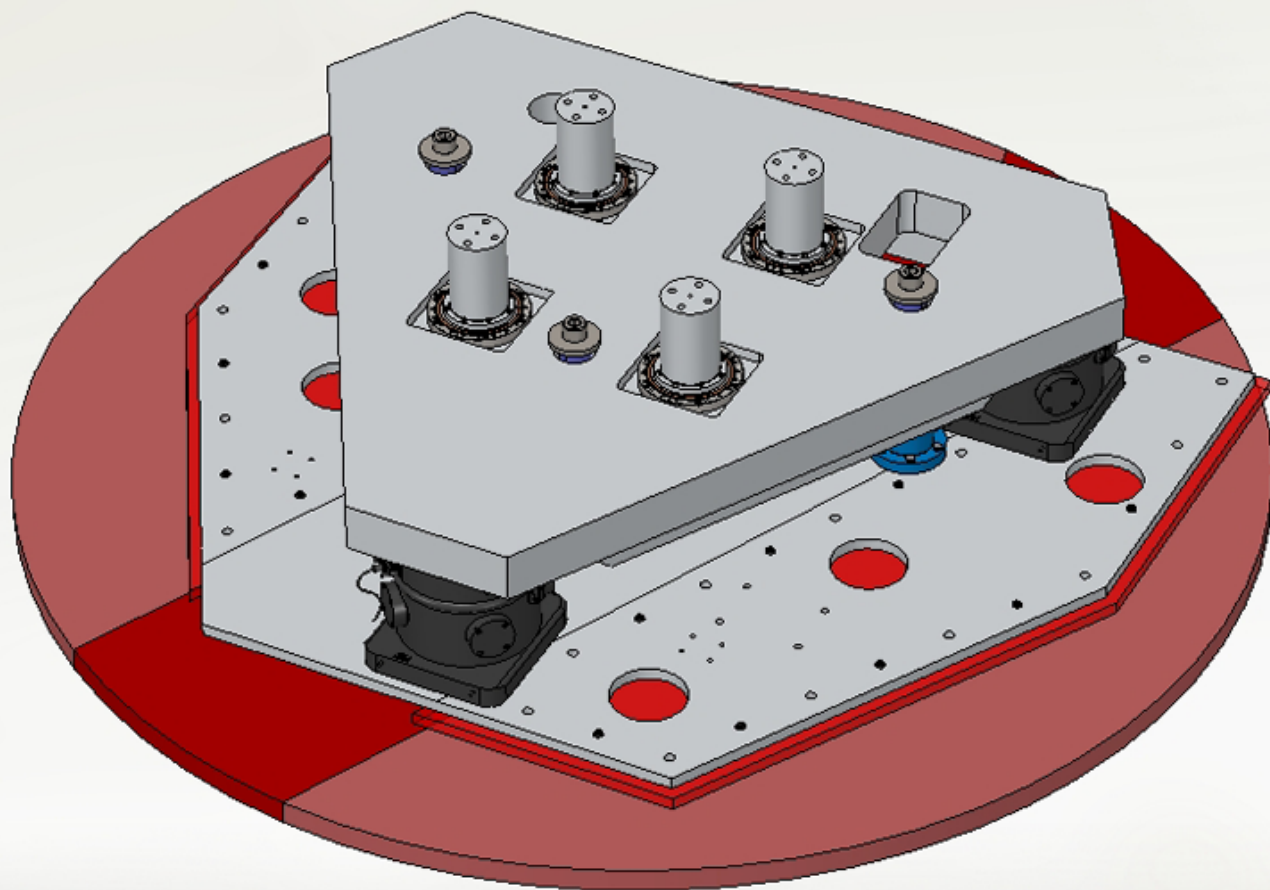


seismic restraints

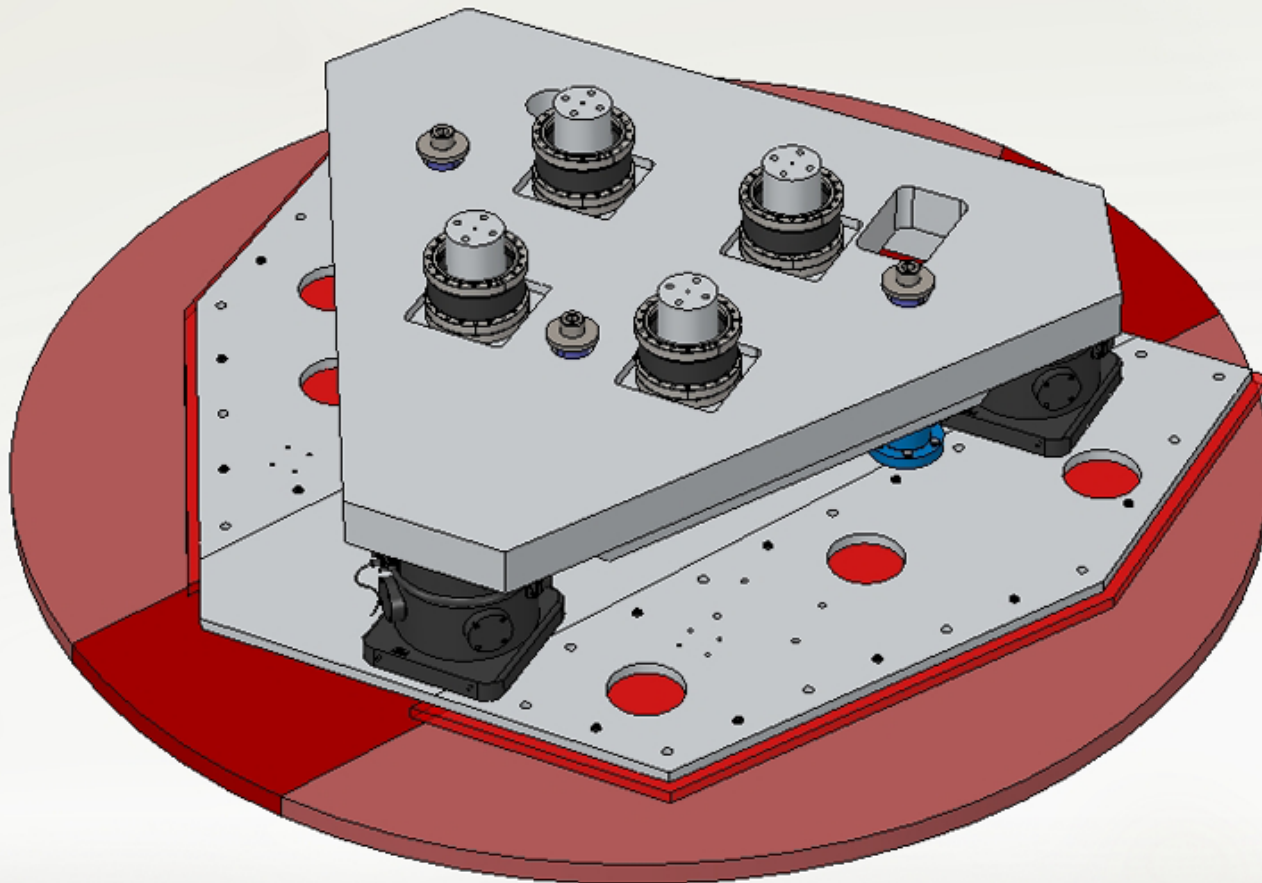


isolated platform

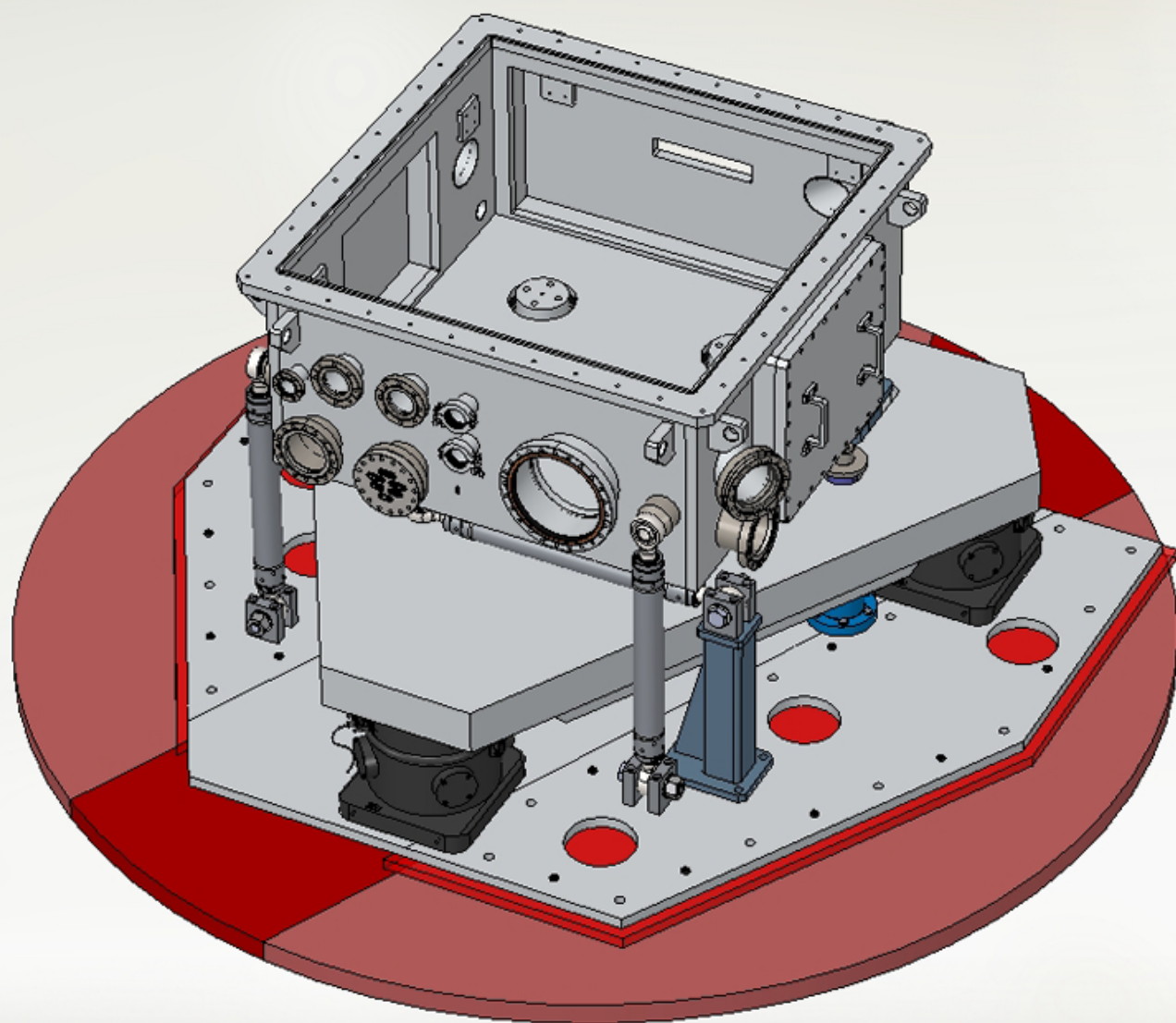




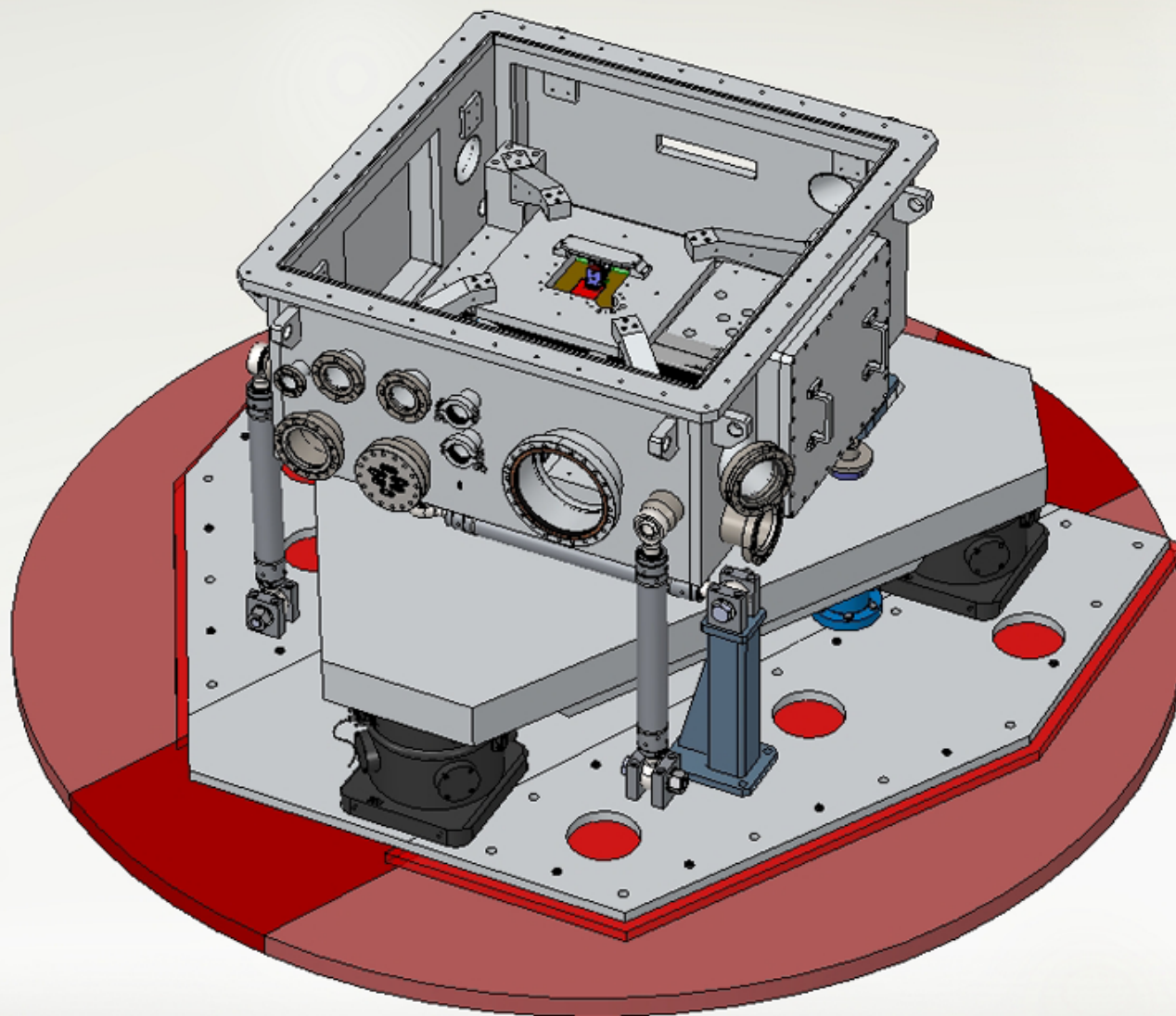
pillars



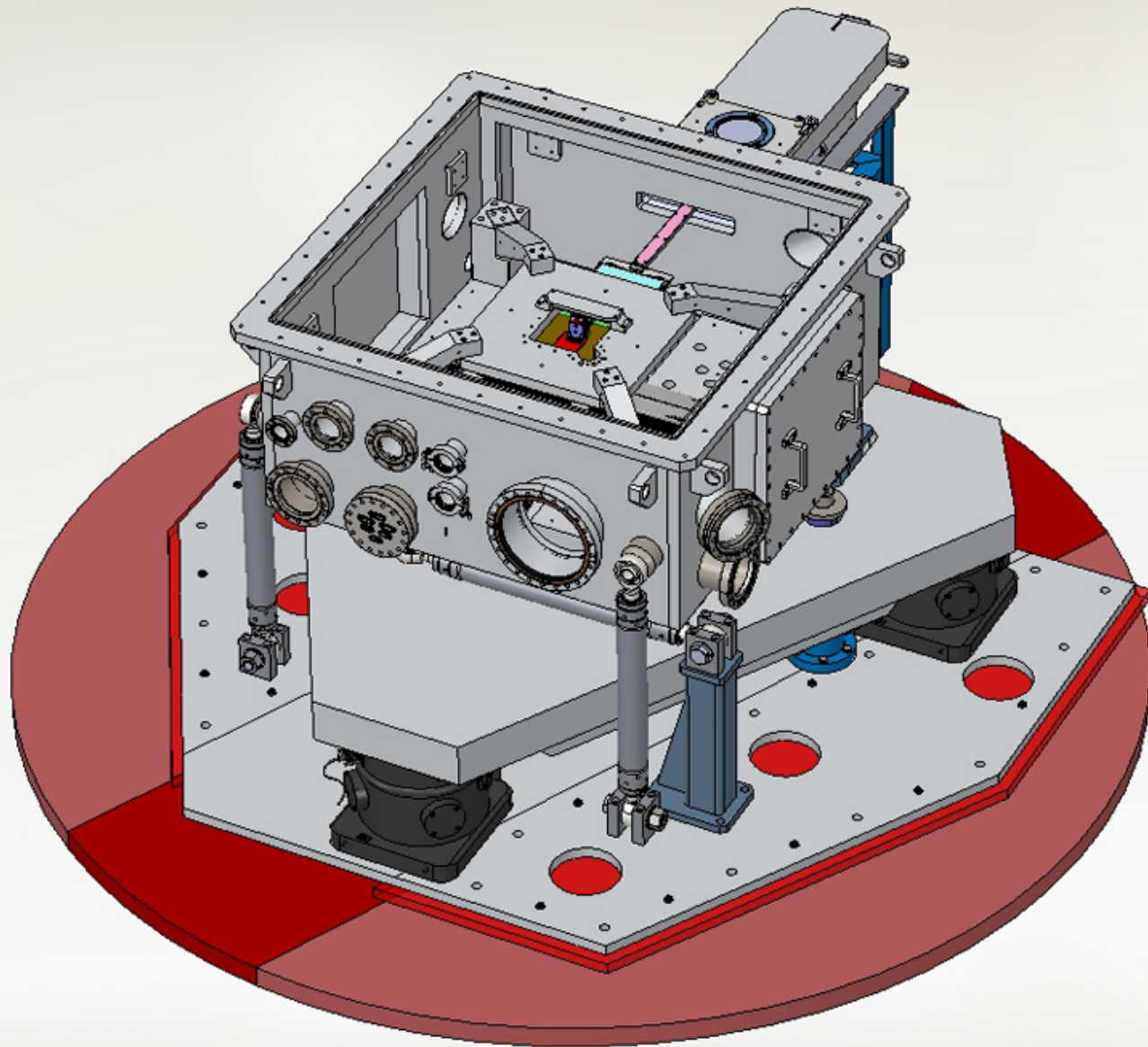
Bellows: Mewasa DN160CF-Compensator



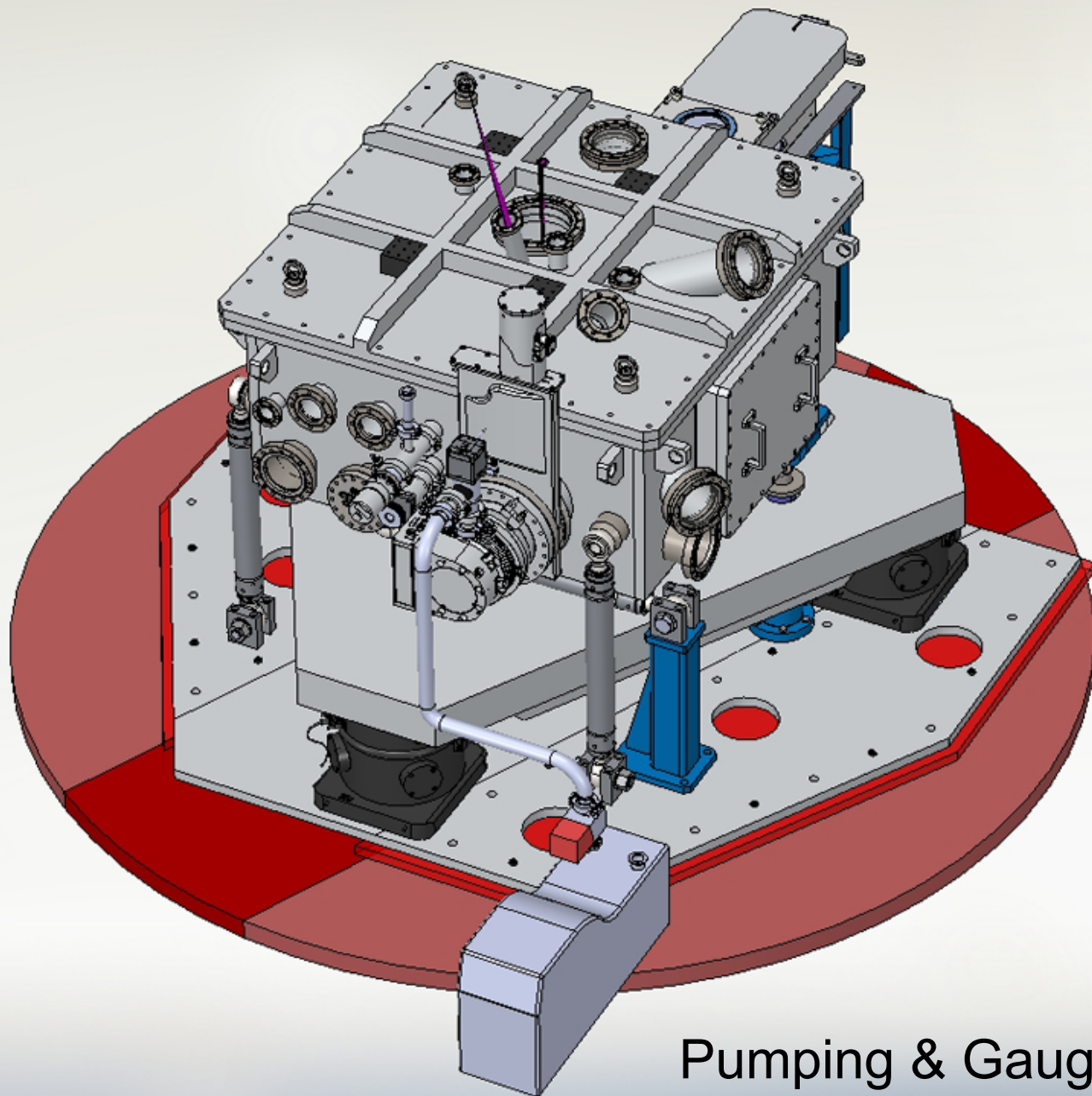




PiMiCos stages

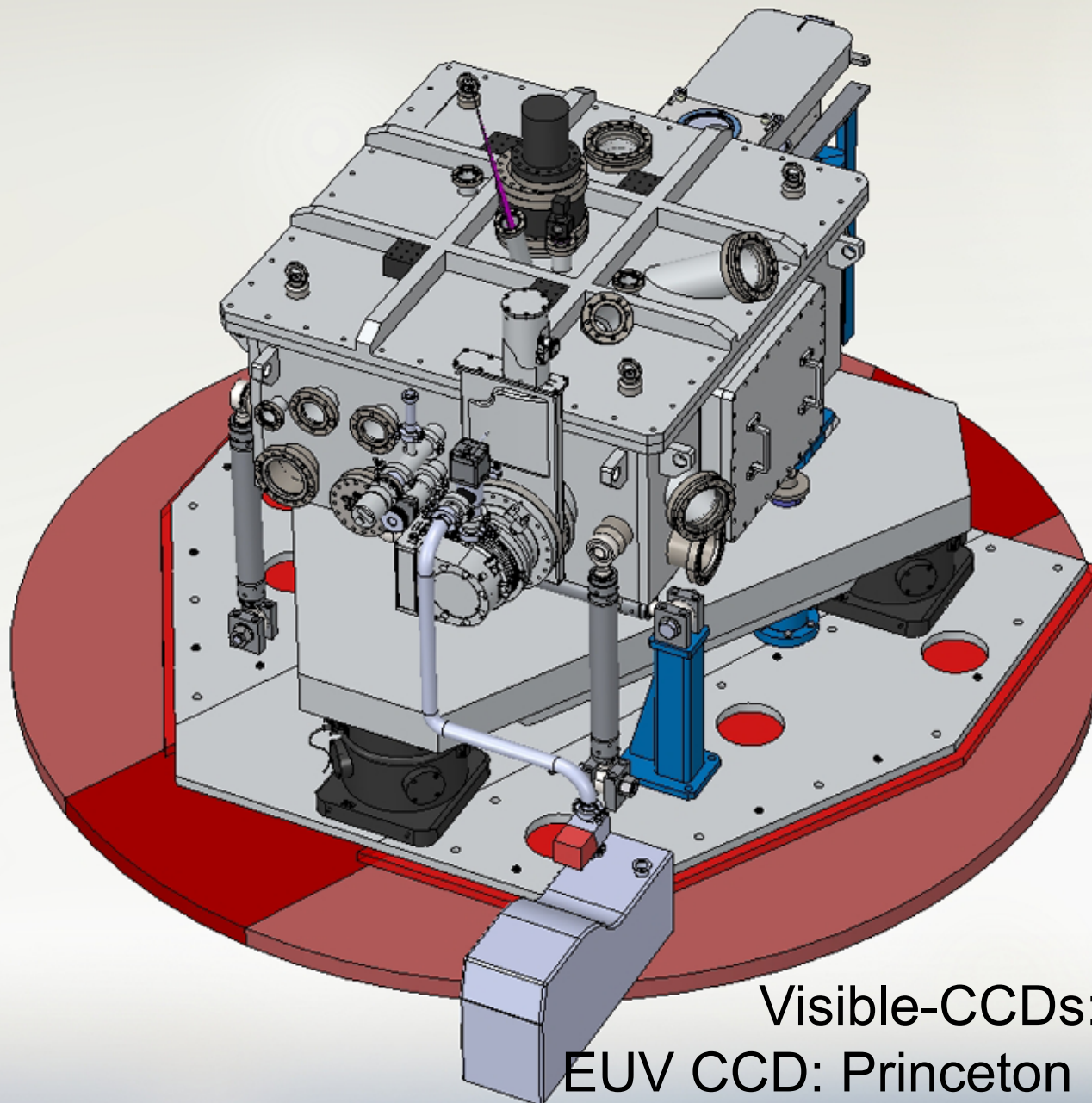


Load Lock: Transfer Engineering TEAMMATE

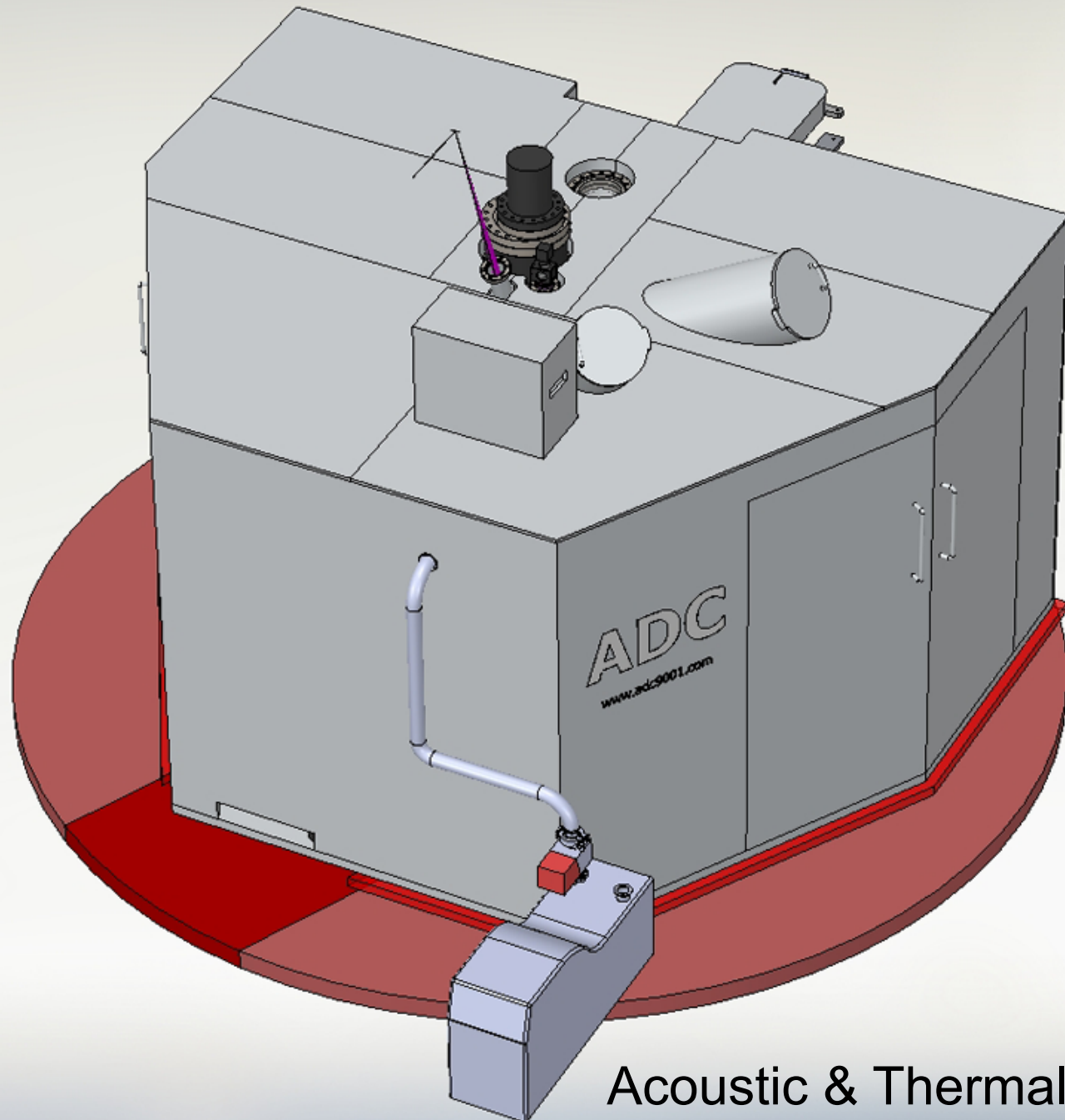


Pumping & Gauges: Pfeiffer

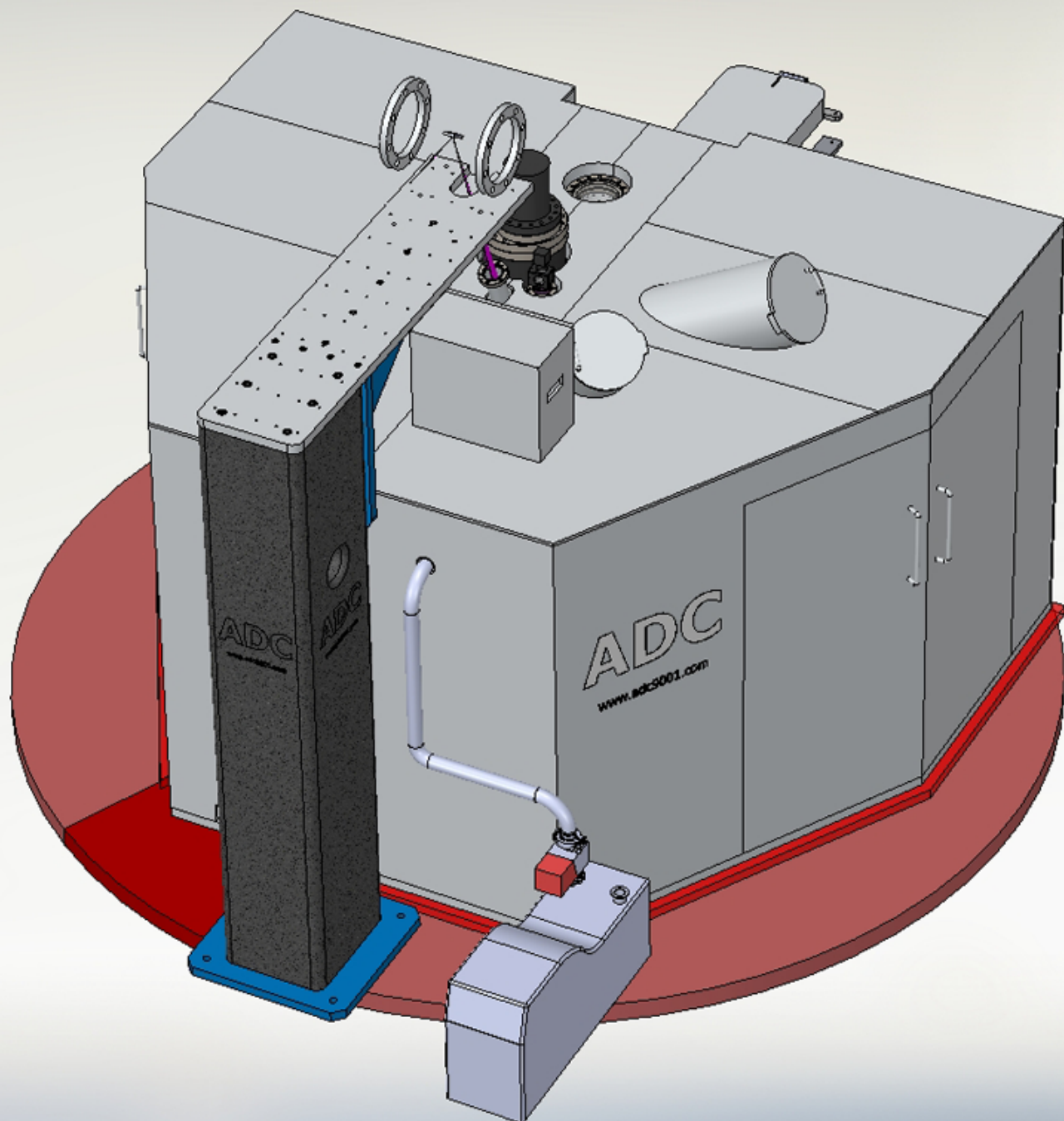




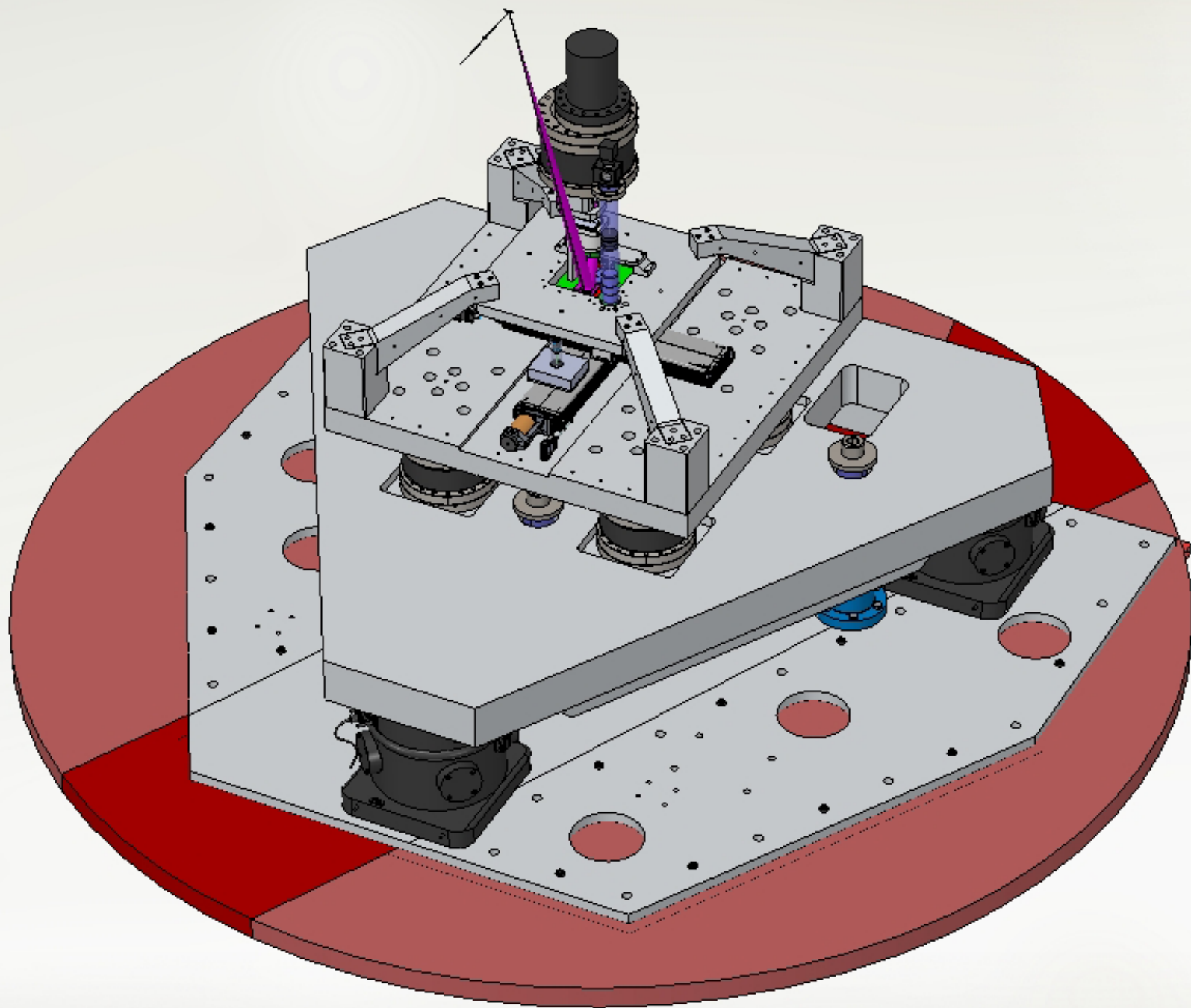
Visible-CCDs: Point Grey  
EUV CCD: Princeton Instruments

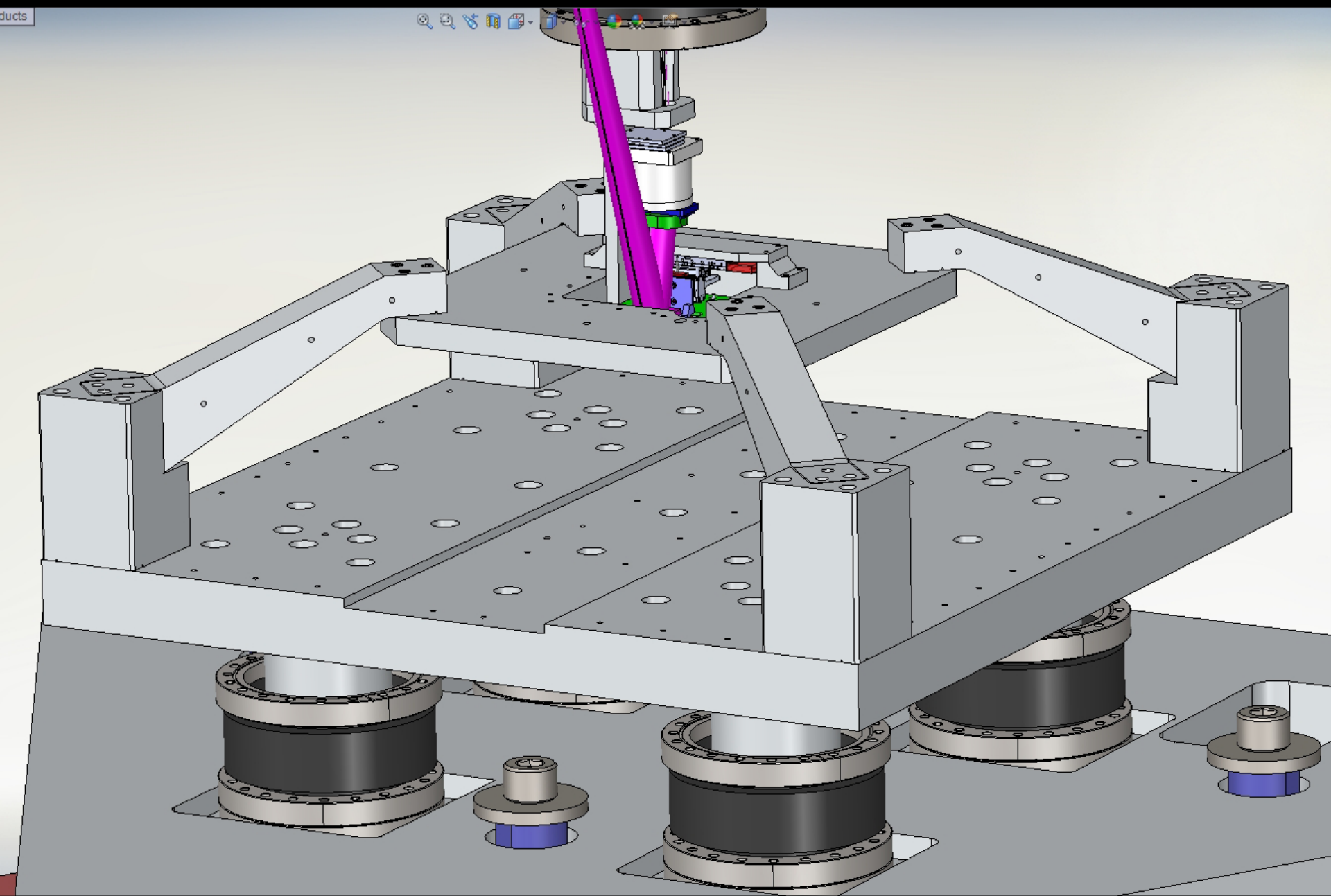


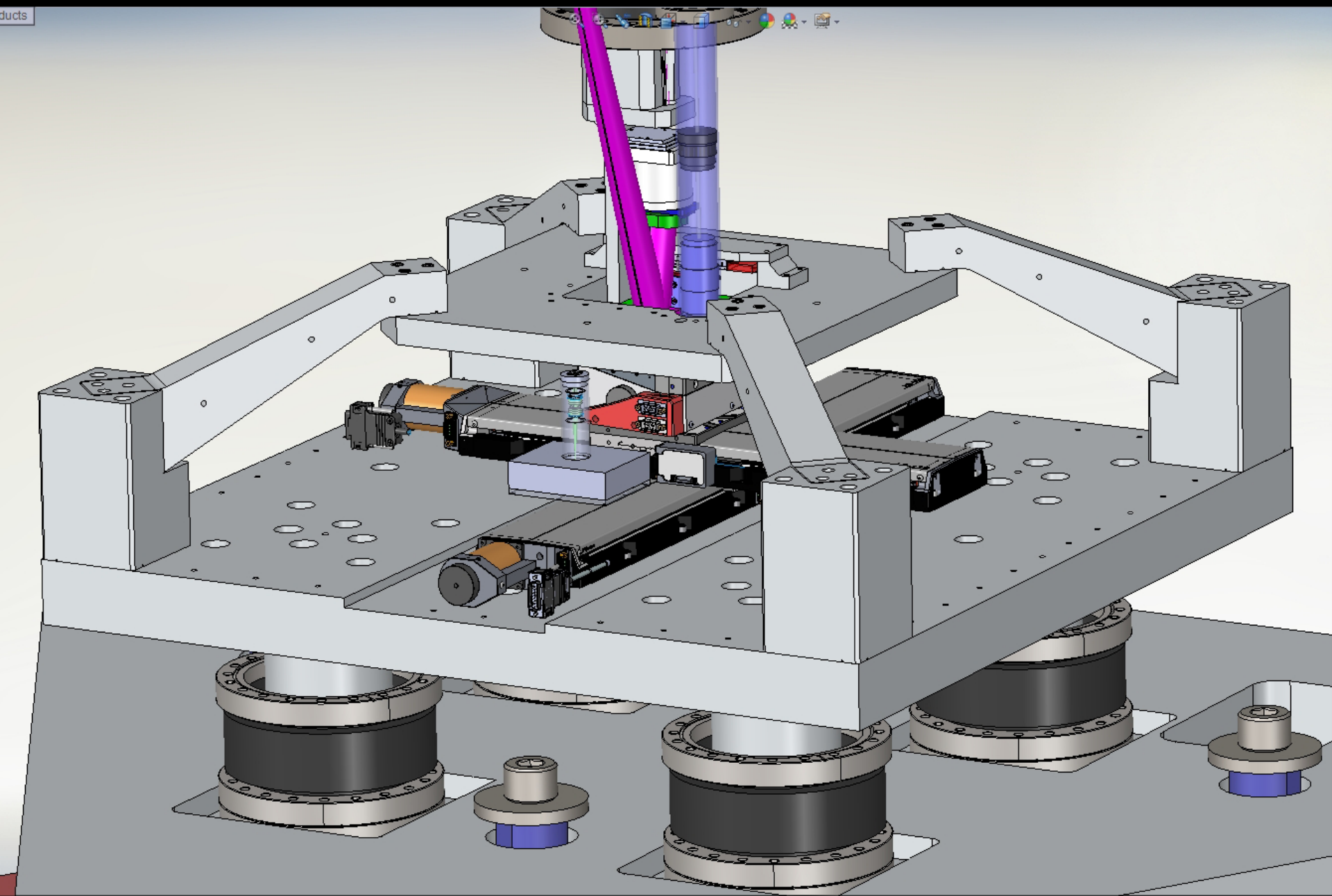
Acoustic & Thermal Enclosure



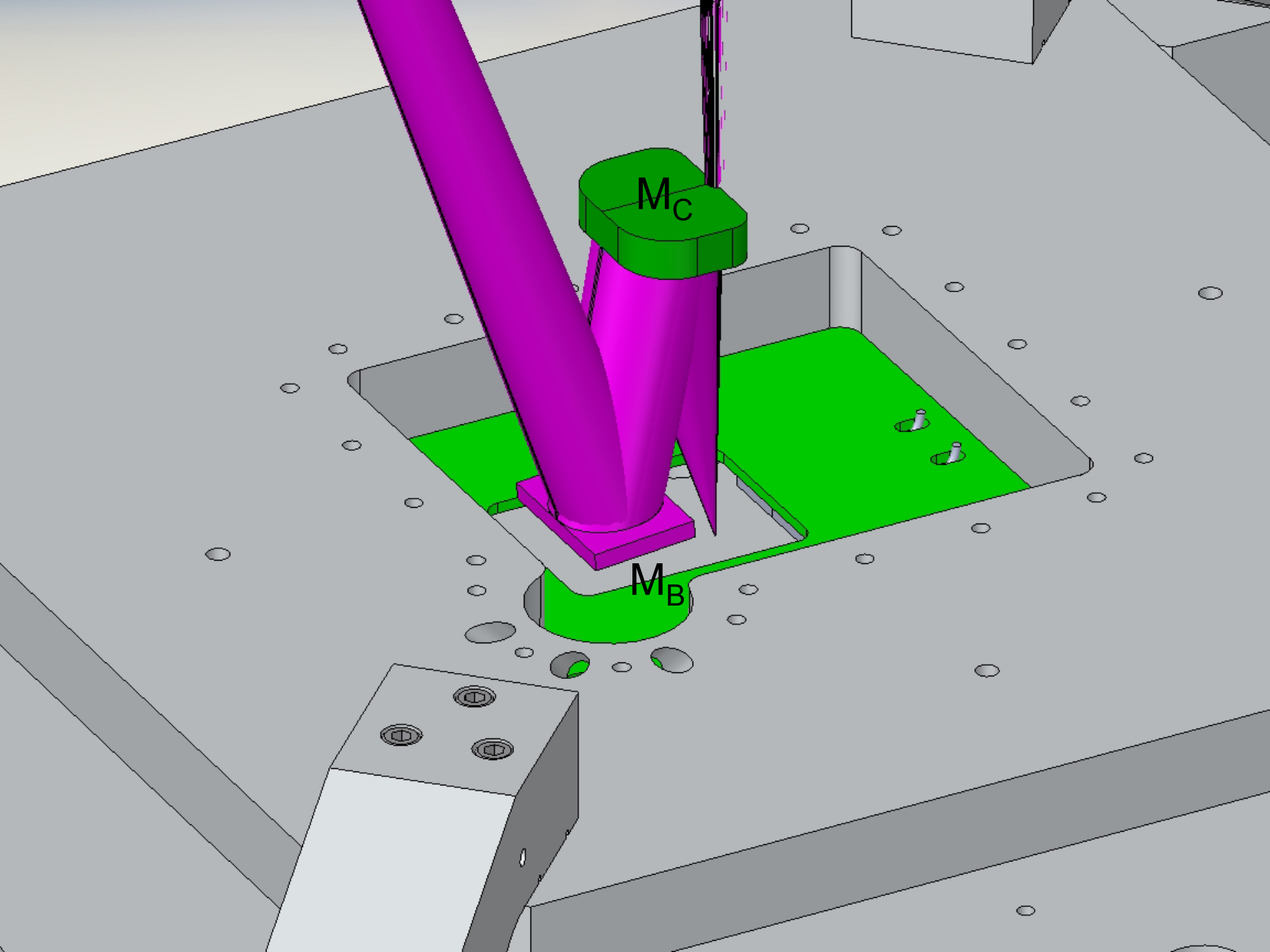


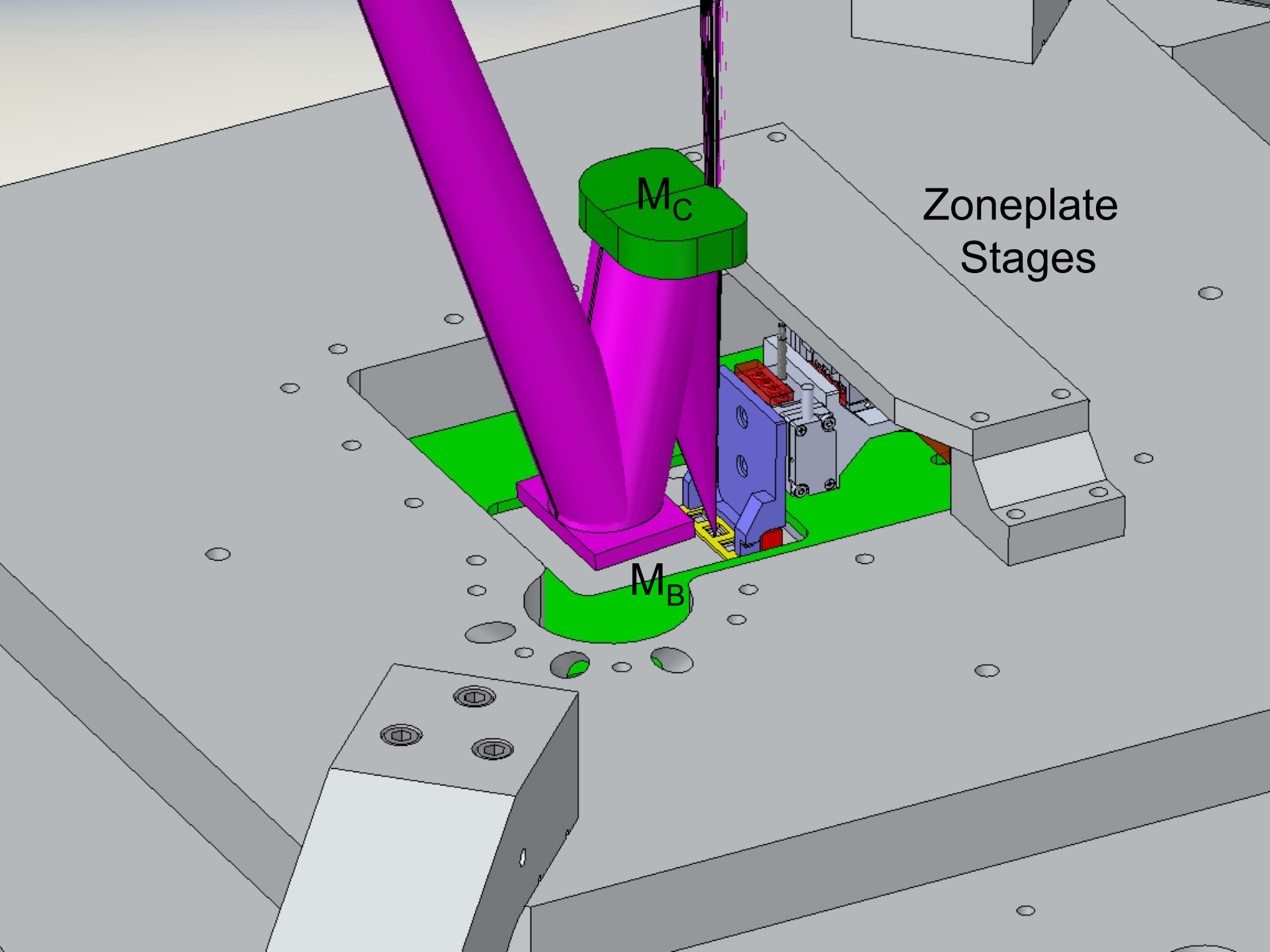








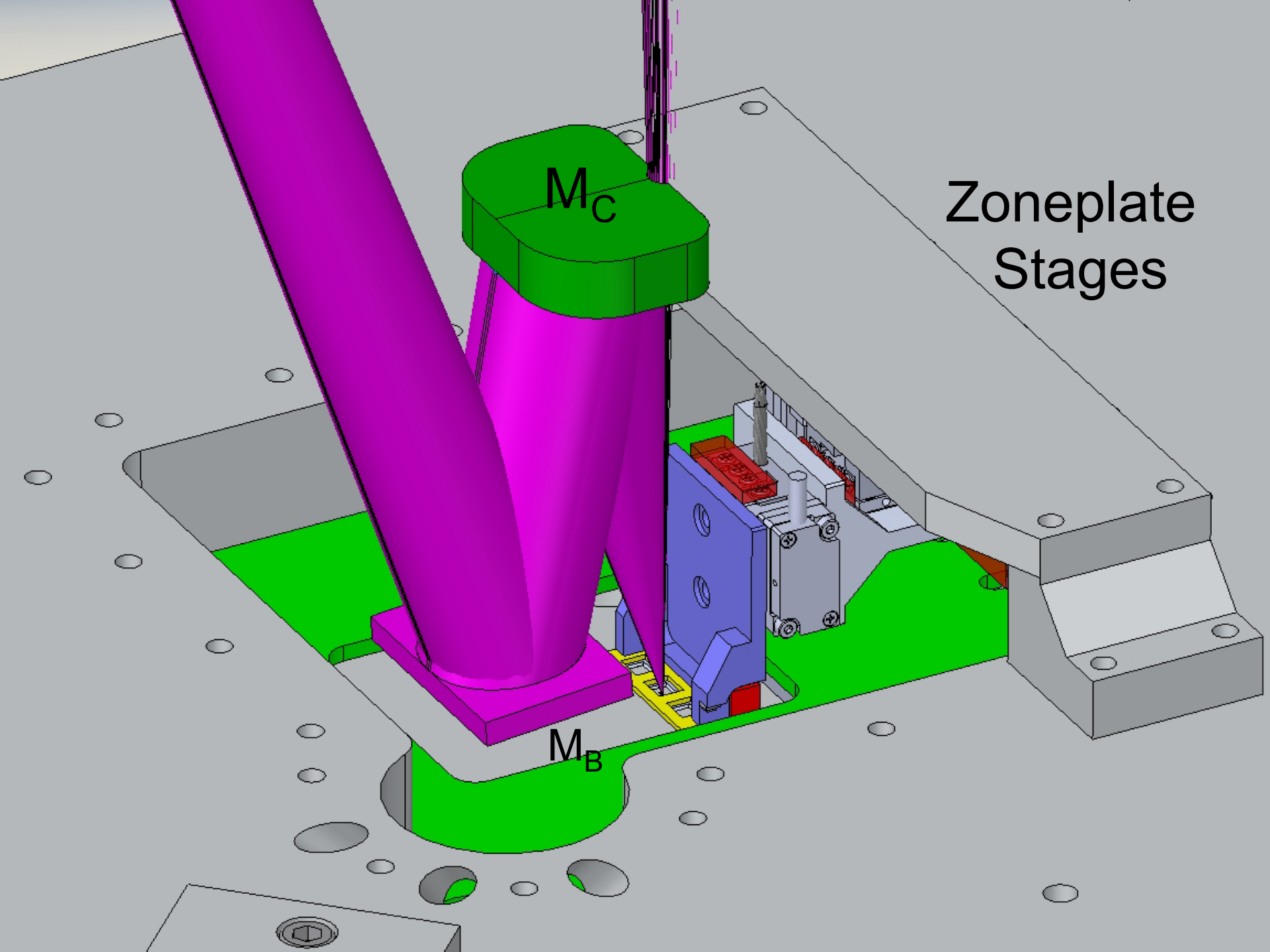




$M_C$

Zoneplate  
Stages

$M_B$



$M_C$

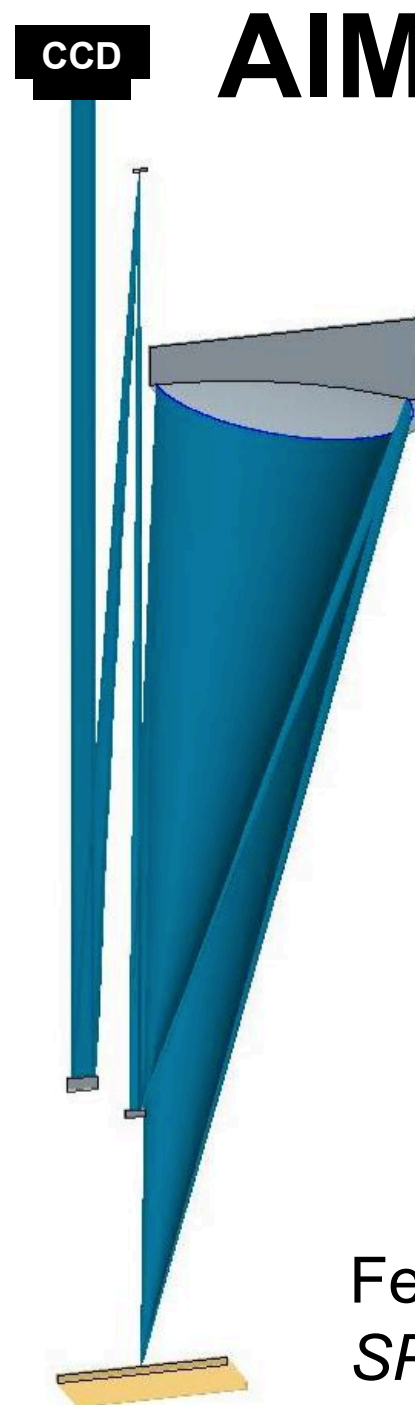
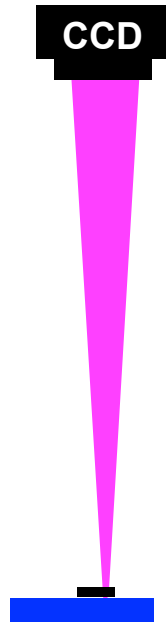
Zoneplate  
Stages

$M_B$



**SHARP**  
SEMATECH  
& LBNL

**CCD** **AIMS™ EUV**  
Zeiss



Feldmann,  
*SPIE 7636* (2010)



Goldberg



Mochi



Benk



Macdougall



Rekawa



Allezy



Dickinson



Smith



Cork



Cork



Salmassi



Huang



Anderson



Chao



Gullikson



Gamsby



Naulleau

# AIT

$> 16 \text{ nm}$

low  $\sigma$

$\angle 6^\circ$

# SHARP

$> 6 \text{ nm}$

any  $\sigma$

up to  $\angle 10^\circ$

# **ACKNOWLEDGMENT**

**SEMATECH: Bryan Rice, David Chan\*, Stefan Wurm, Harry Kwon**

visit  
**SHARP.lbl.gov**

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